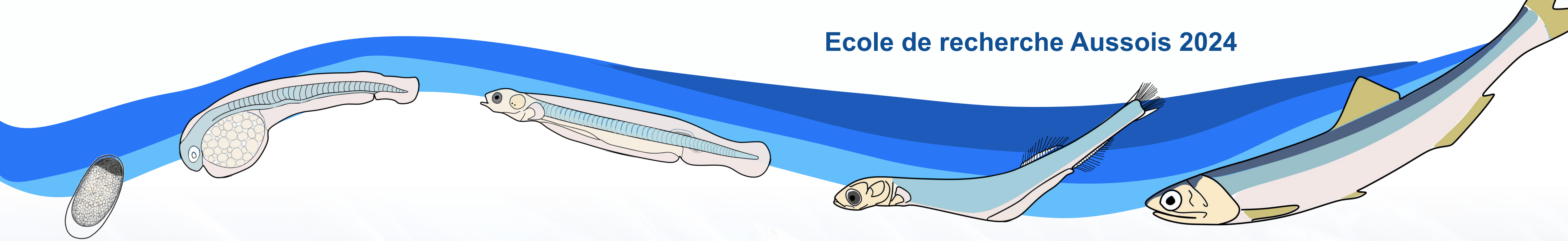
Ecole de recherche Aussois 2024



A generalized Dynamic Energy Budget model including 3D shape changes for modeling small pelagic fish growth

Lola De Cubber, Grea Groenewald, Matthew Horton, Laure Pecquerie, Martin Huret, Carl van der Lingen and Olivier Maury

marbec marine biodiversity exploitation & conservation
l'X École Polytechnique
Modélisation Mathématique et Biodiversité
agriculture, forestry & fisheries
Department: Agriculture, Forestry and Fisheries
REPUBLIC OF SOUTH AFRICA
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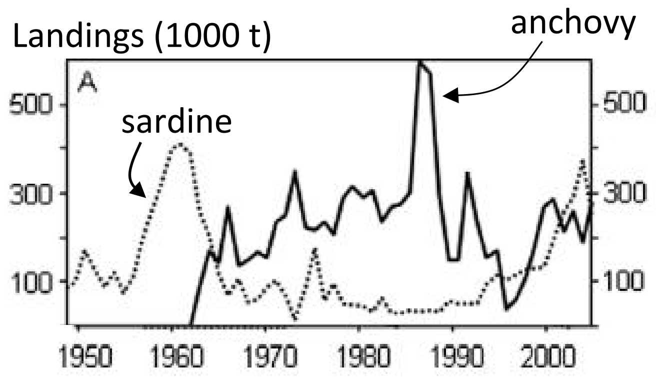
Introduction

Context

Stock variability

Marine Ecosystems

Food security



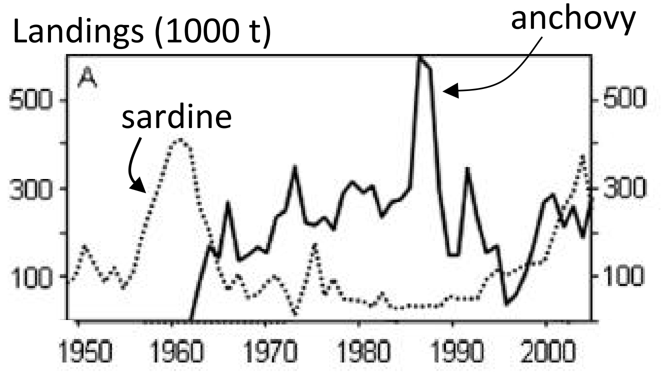
South Africa, Barange et al. (2009)

Introduction *Context*

Marine Ecosystems

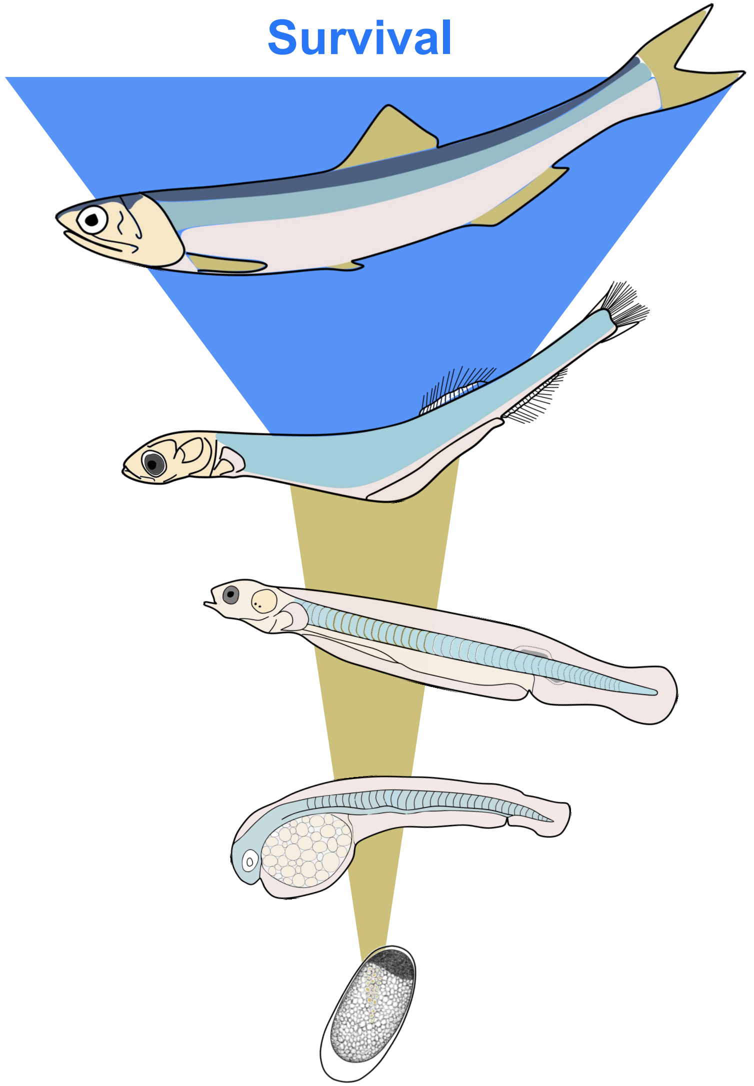
Food security

Stock variability



South Africa, Barange et al. (2009)

Survival



Introduction

Context

Marine Ecosystems

Food security

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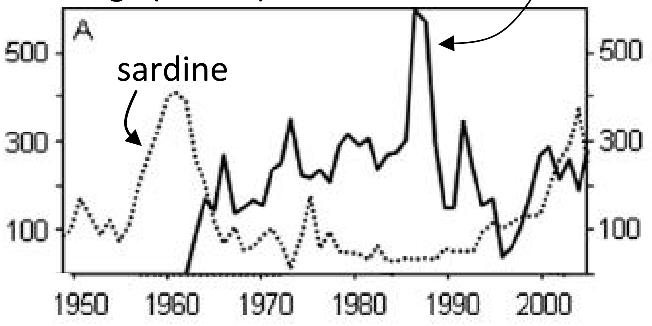
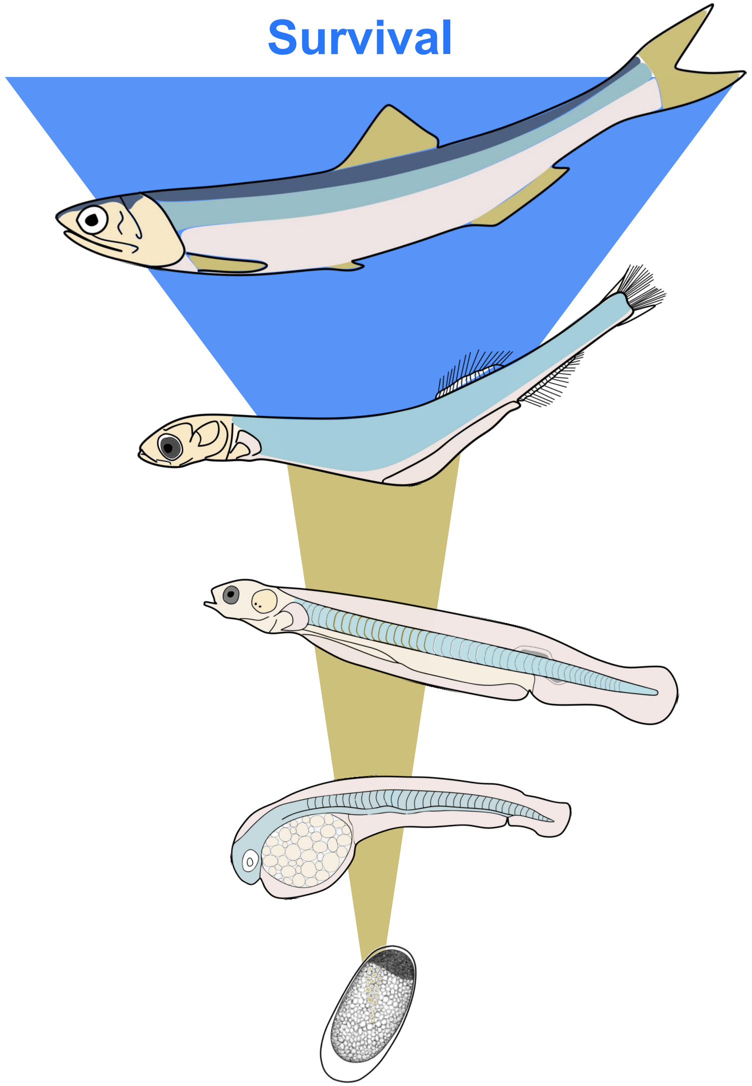
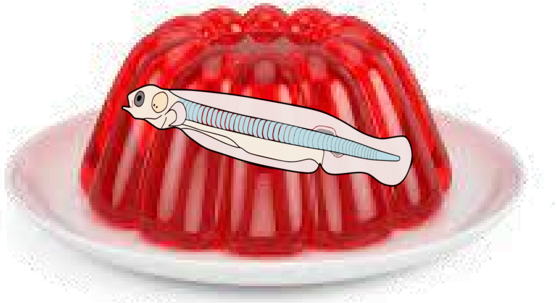


South Africa, Barange et al. (2009)

Survival

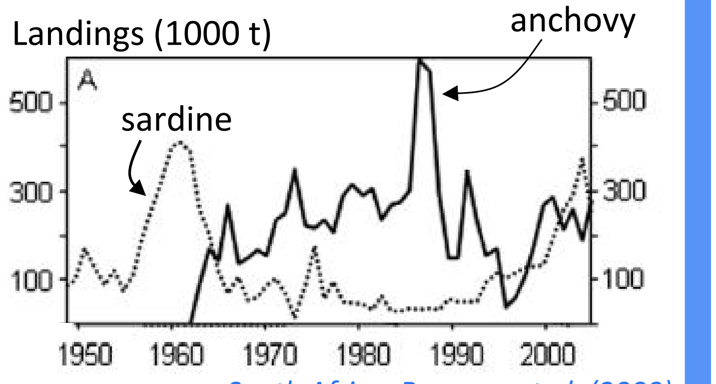




Introduction

Context

Stock variability

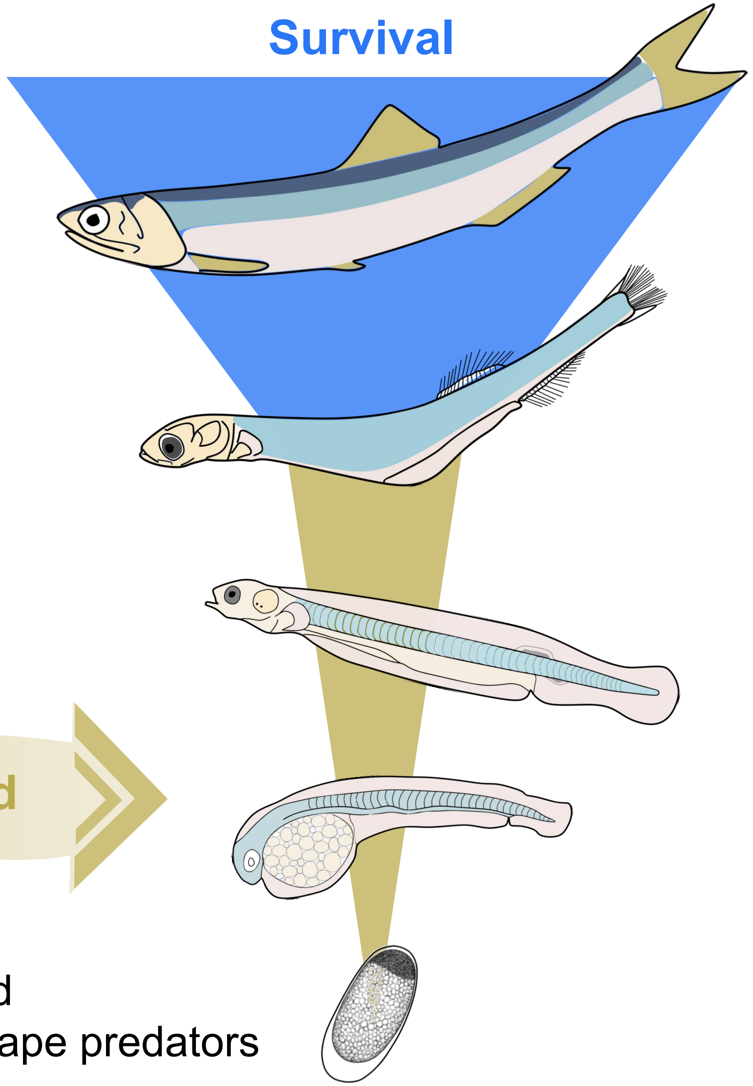


South Africa, Barange et al. (2009)

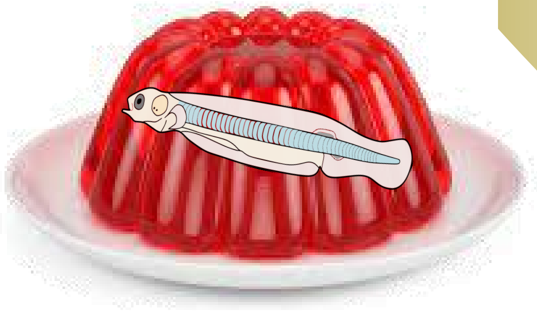
Marine Ecosystems

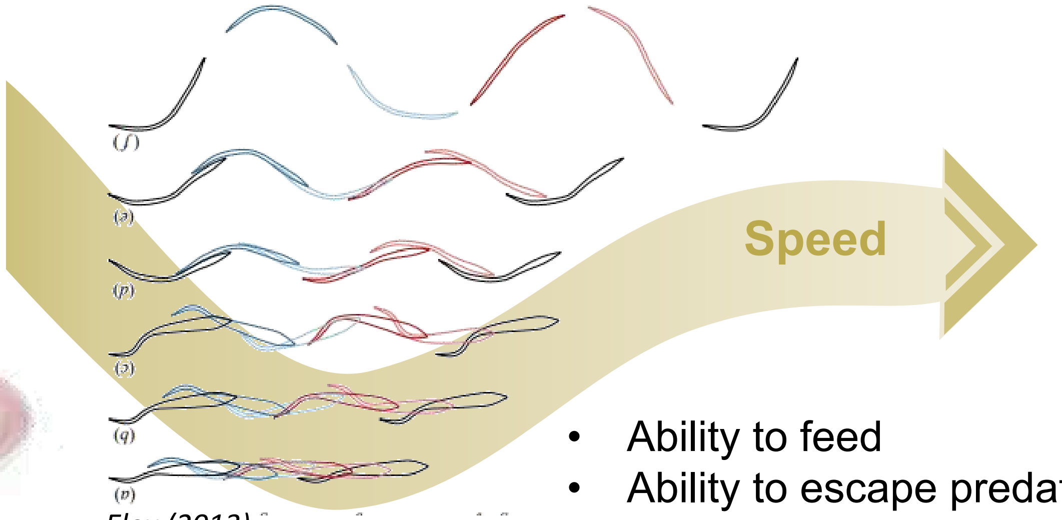
Food security

Survival



Growth and shape evolution





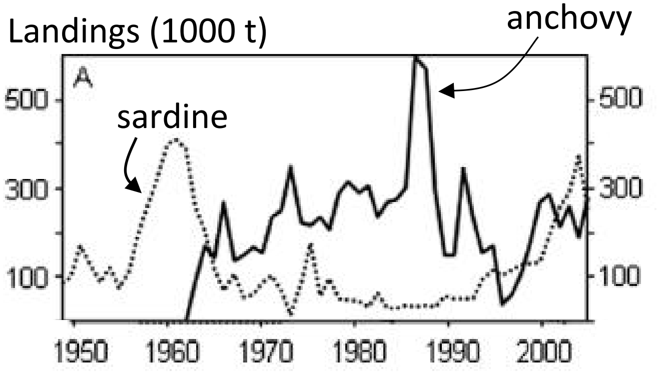
Eloy (2013)

- Ability to feed
- Ability to escape predators

Introduction

Context

Stock variability

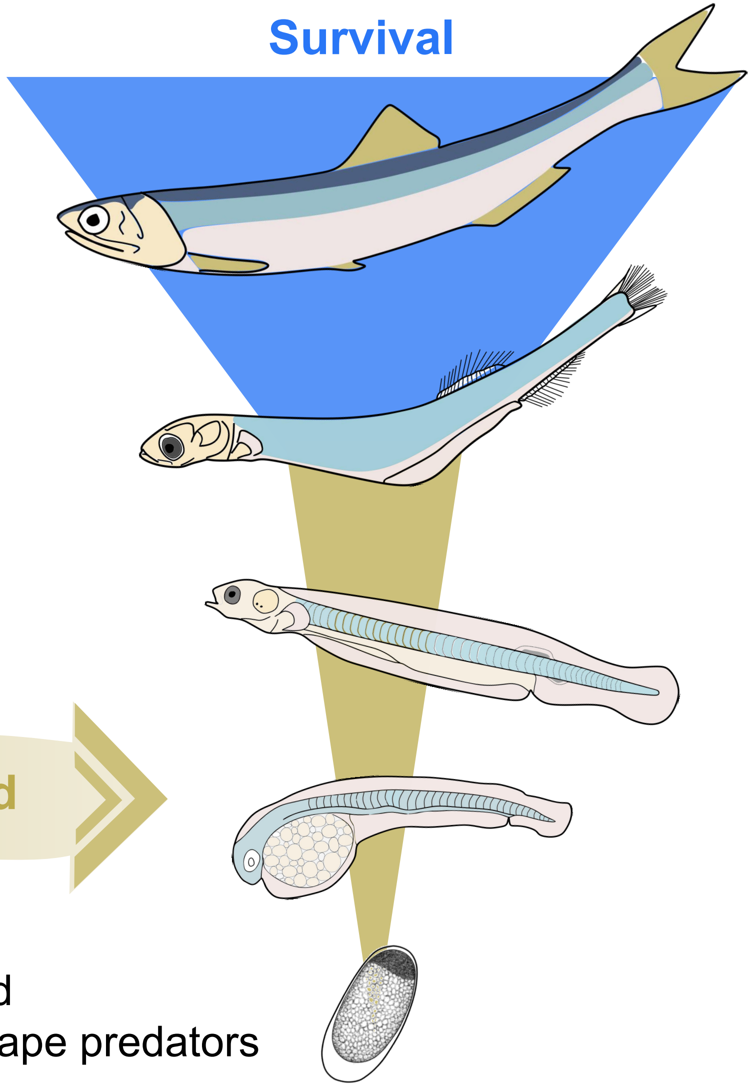


South Africa, Barange et al. (2009)

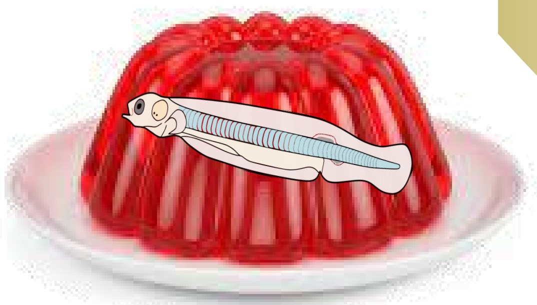
Marine Ecosystems

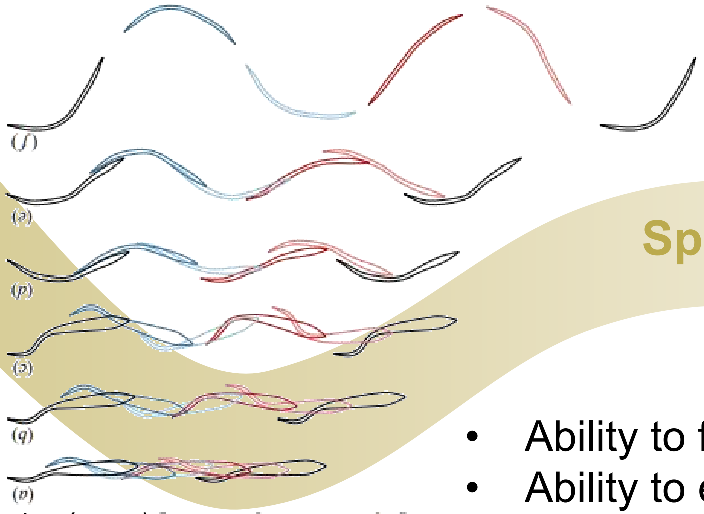
Food security

Survival



Growth and shape evolution





Eloy (2013)

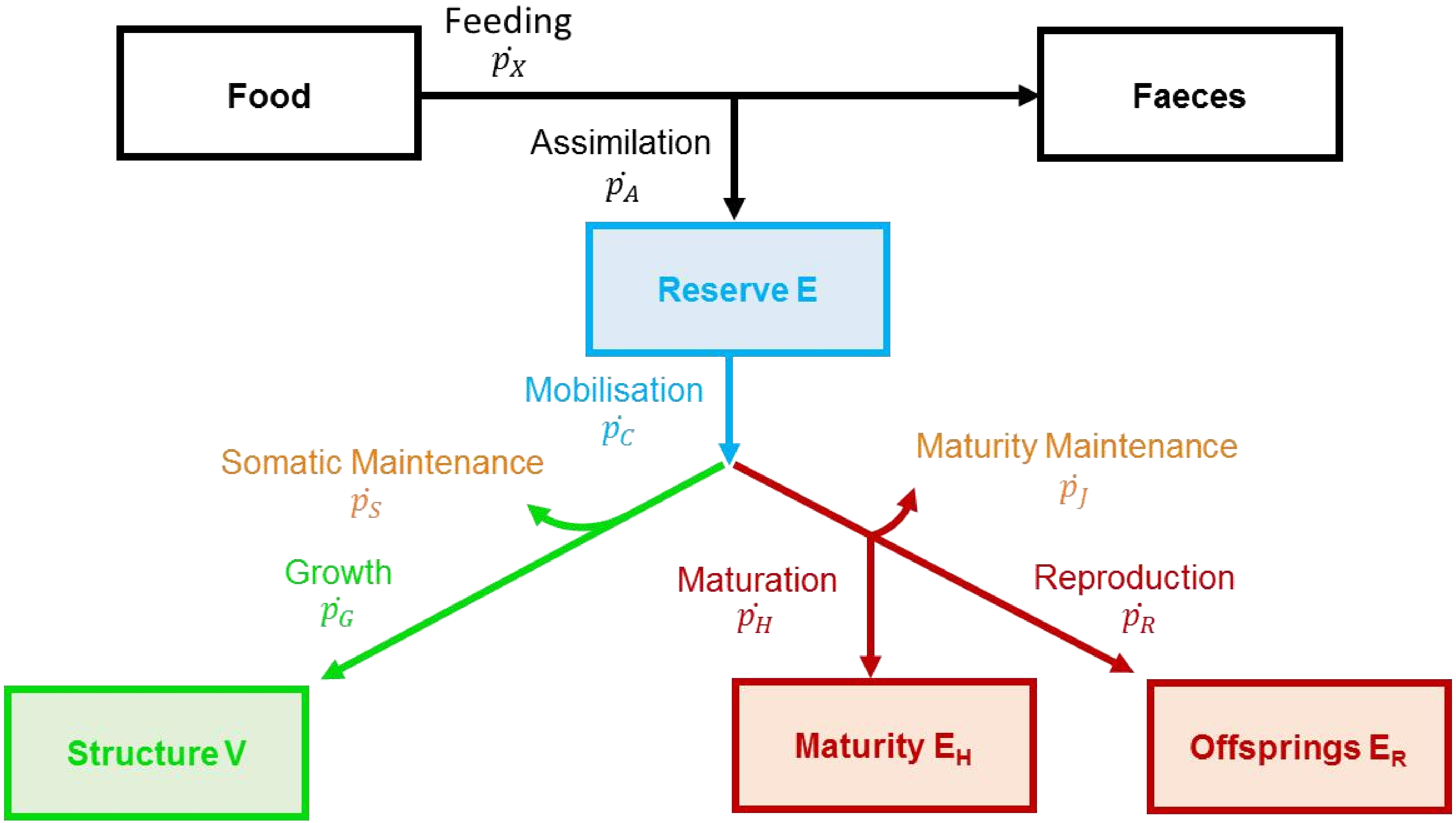
Speed

- Ability to feed
- Ability to escape predators

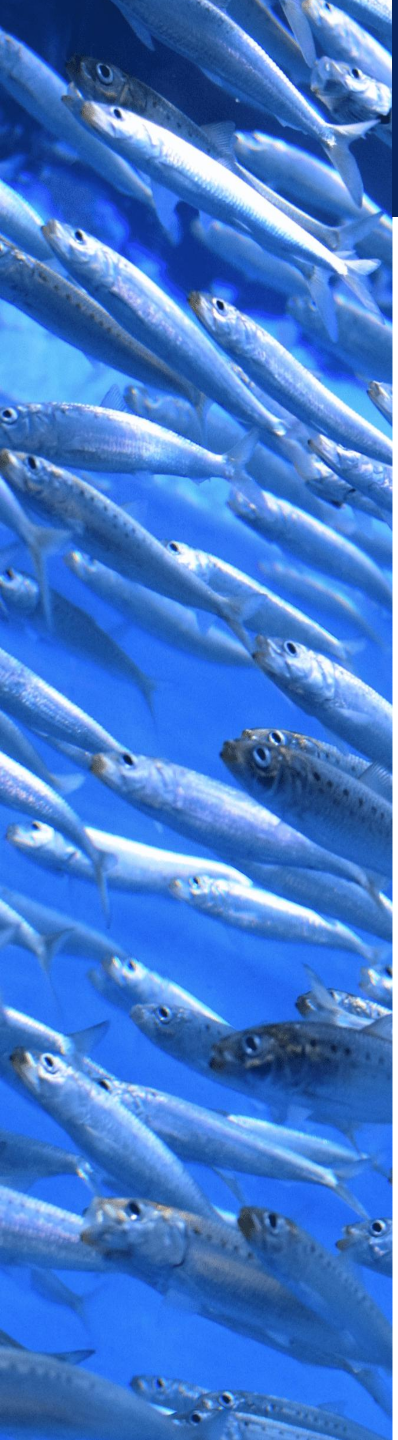
Need for a good representation of growth and shape even for early stages !

Introduction

Existing DEB models

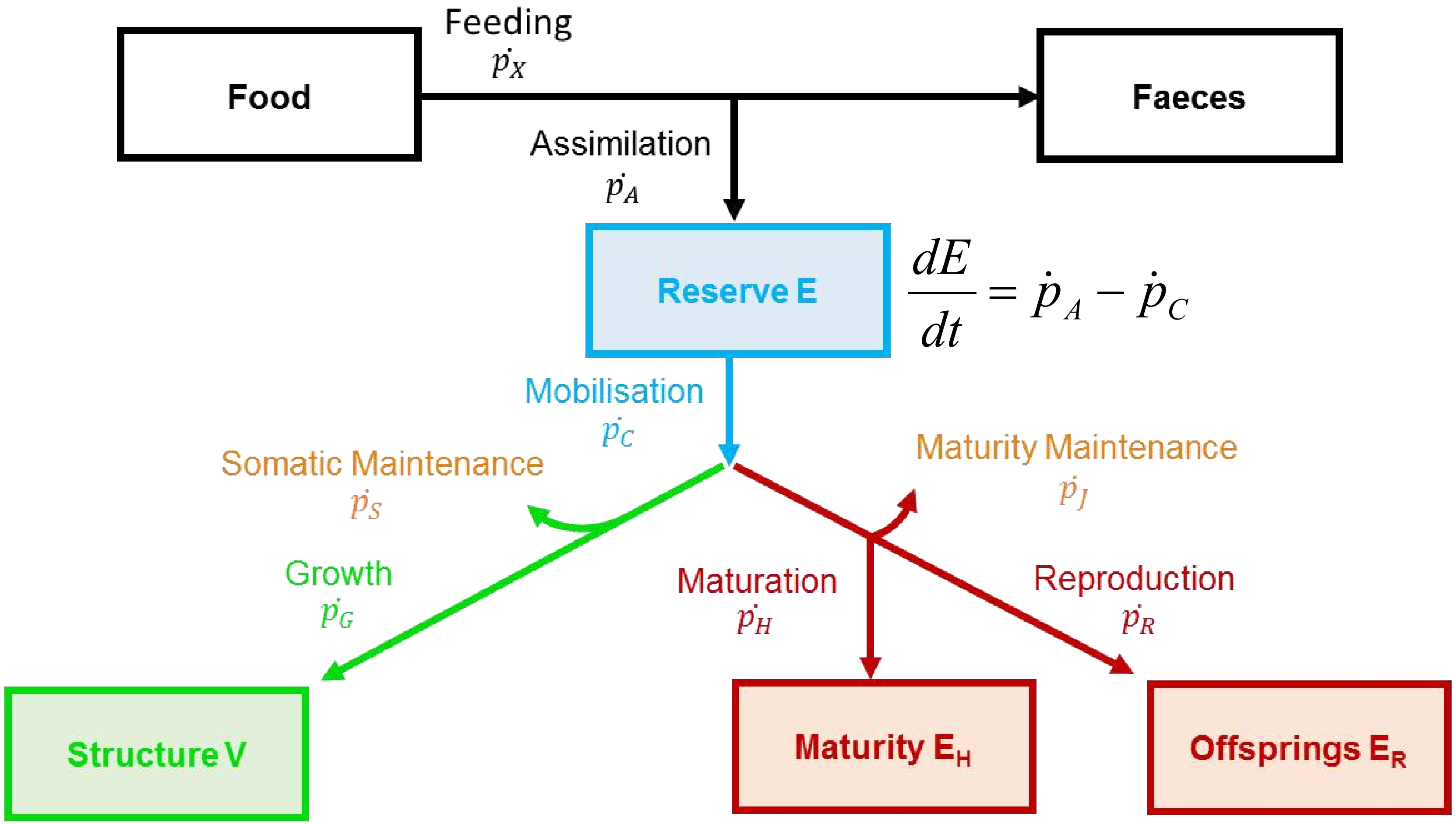


Kooijman (2000)



Introduction

Existing DEB models



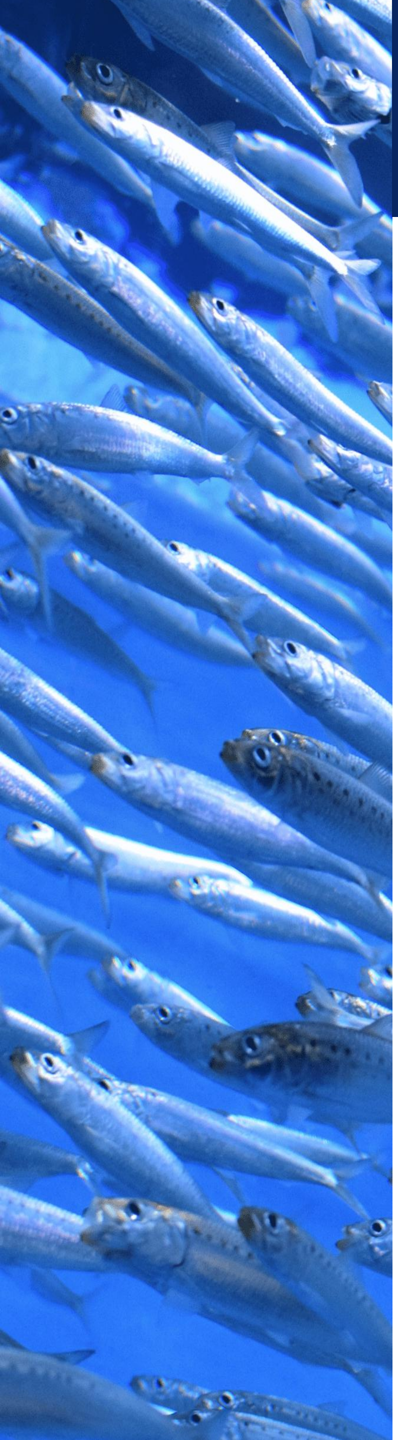
$$\frac{dE}{dt} = \dot{p}_A - \dot{p}_C$$

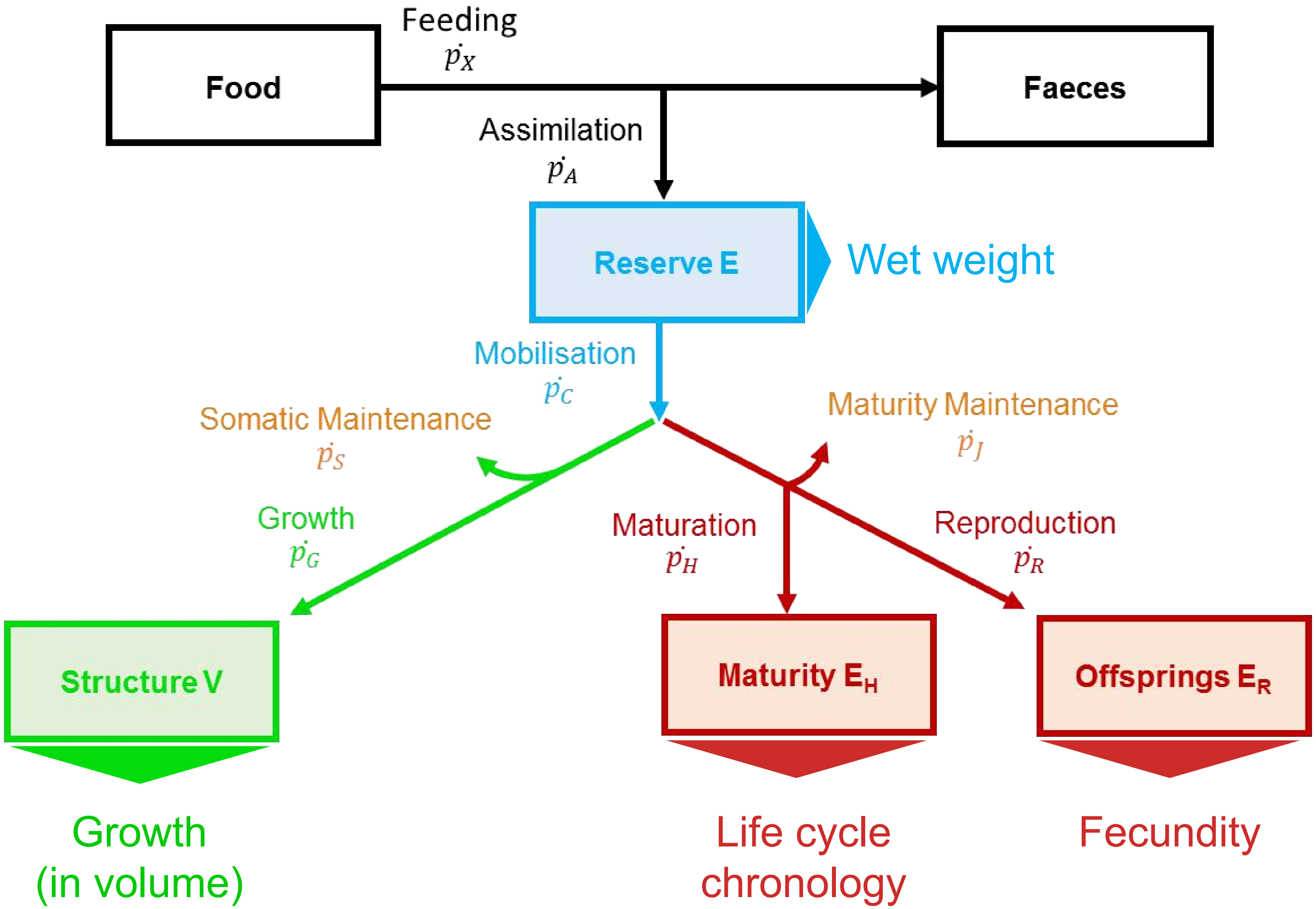
$$\frac{dV}{dt} = \frac{\dot{p}_G}{[E_G]}$$

$$\frac{dE_H}{dt} = \dot{p}_H$$

$$\frac{dE_R}{dt} = \dot{p}_R$$

~ 12 parameters in a standard DEB model



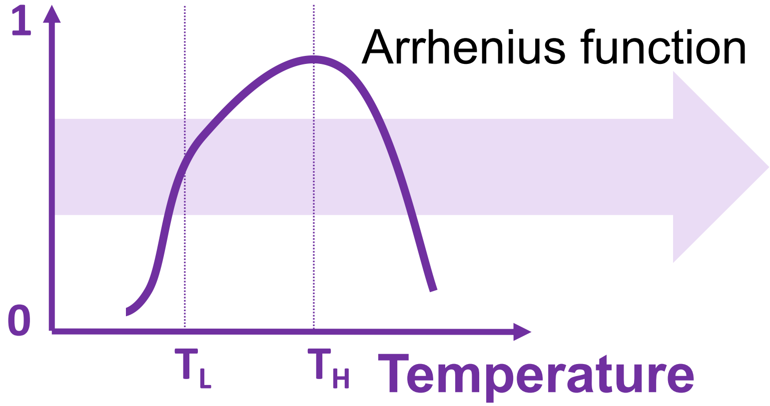


Food
Feeding
$\dot{p}_X$
Faeces
Assimilation
$\dot{p}_A$
Reserve E
Wet weight
Mobilisation
$\dot{p}_C$
Somatic Maintenance
$\dot{p}_S$
Maturity Maintenance
$\dot{p}_J$
Growth
$\dot{p}_G$
Maturation
$\dot{p}_H$
Reproduction
$\dot{p}_R$
Structure V
Maturity E_H
Offsprings E_R
Growth
(in volume)
Life cycle
chronology
Fecundity

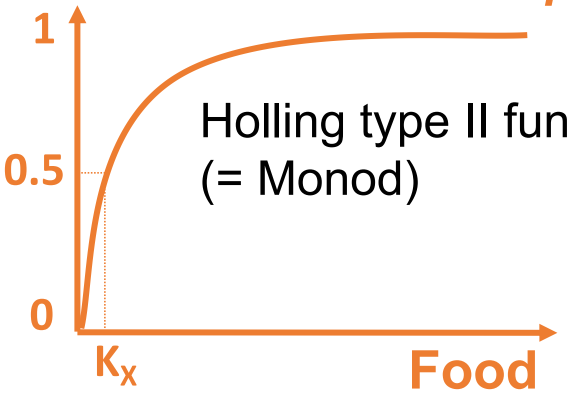
Introduction

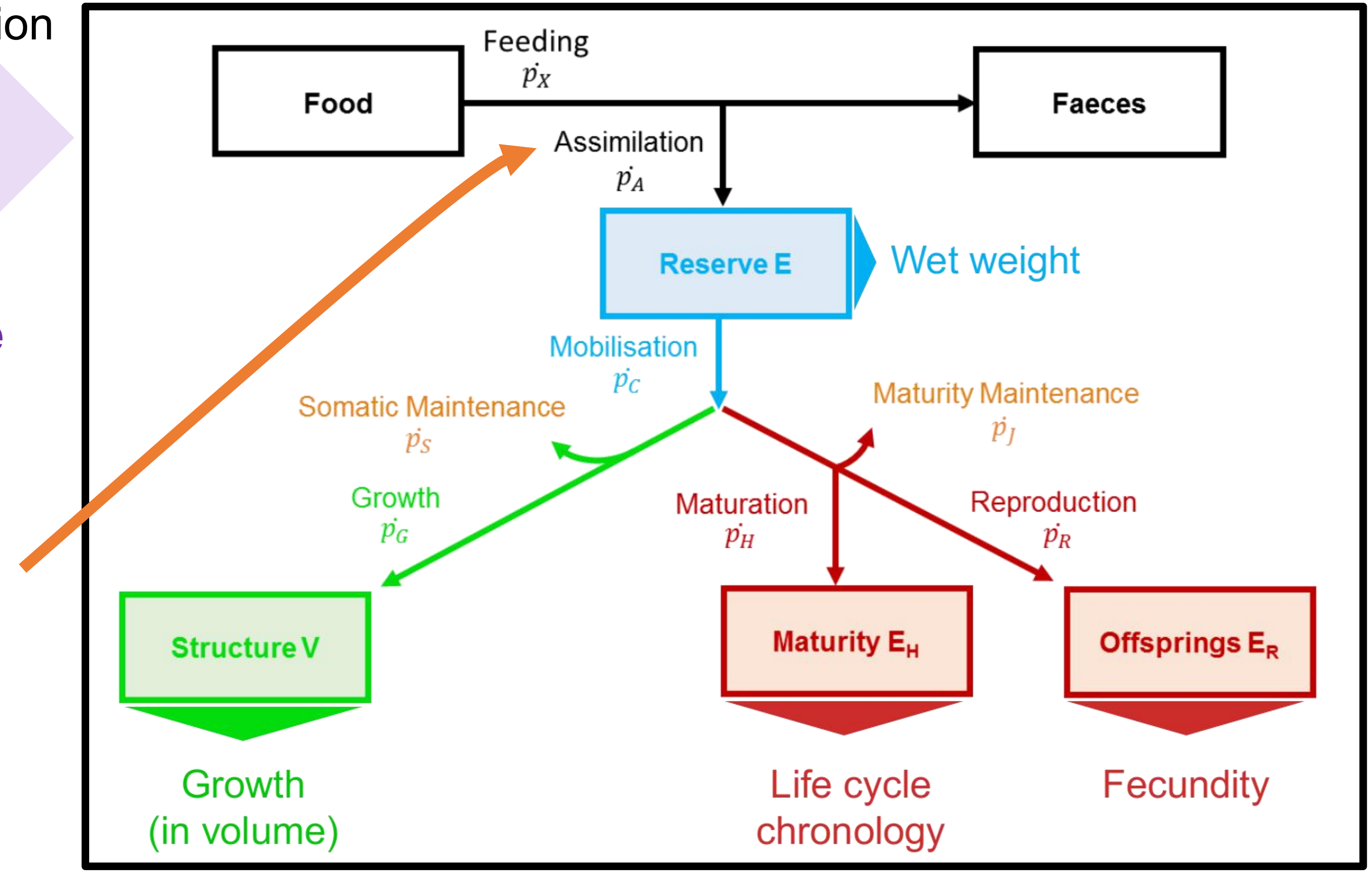
Existing DEB models

Temperature correction to the metabolic rates



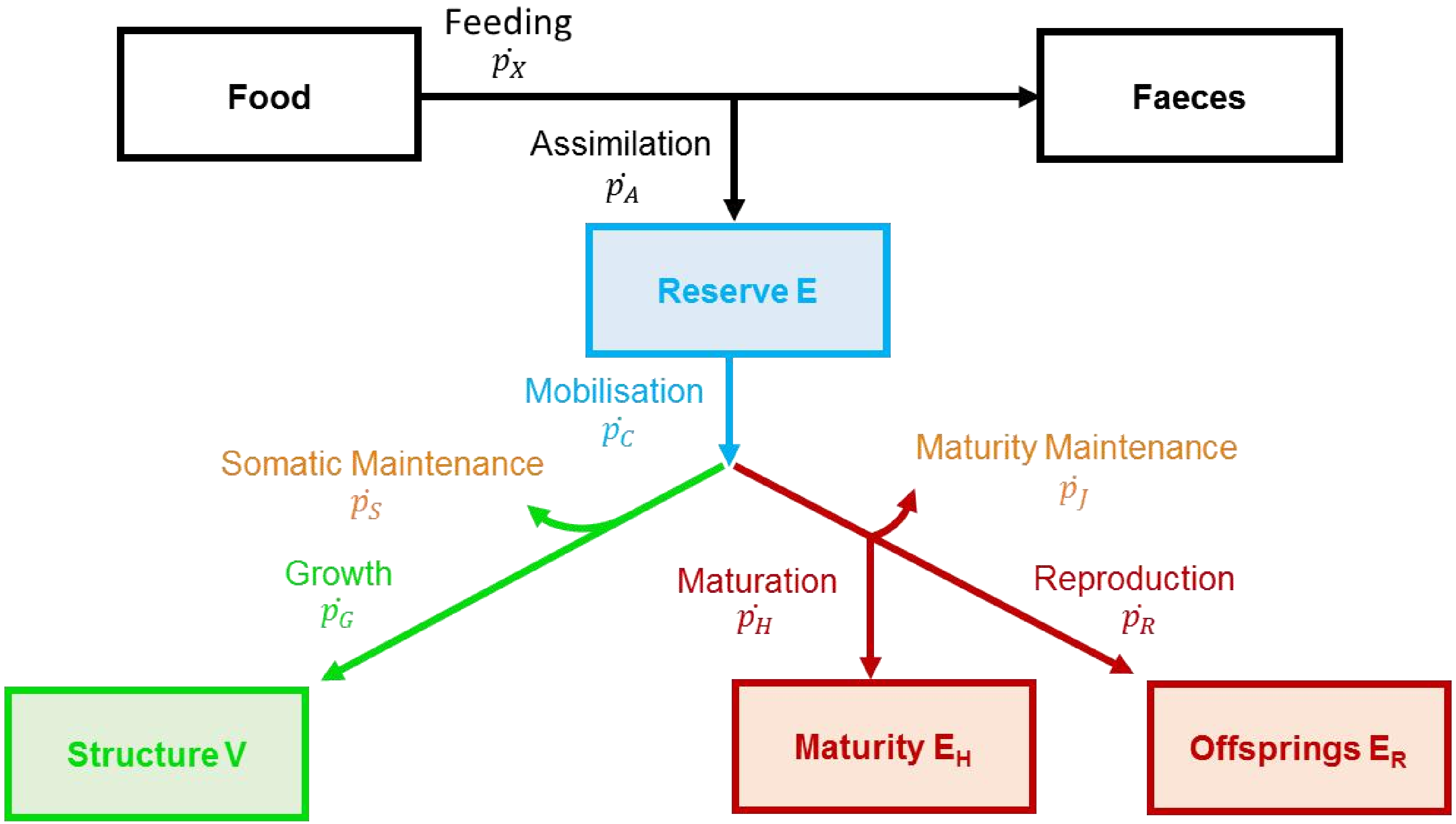
Scaled functional response





Introduction

Existing DEB models

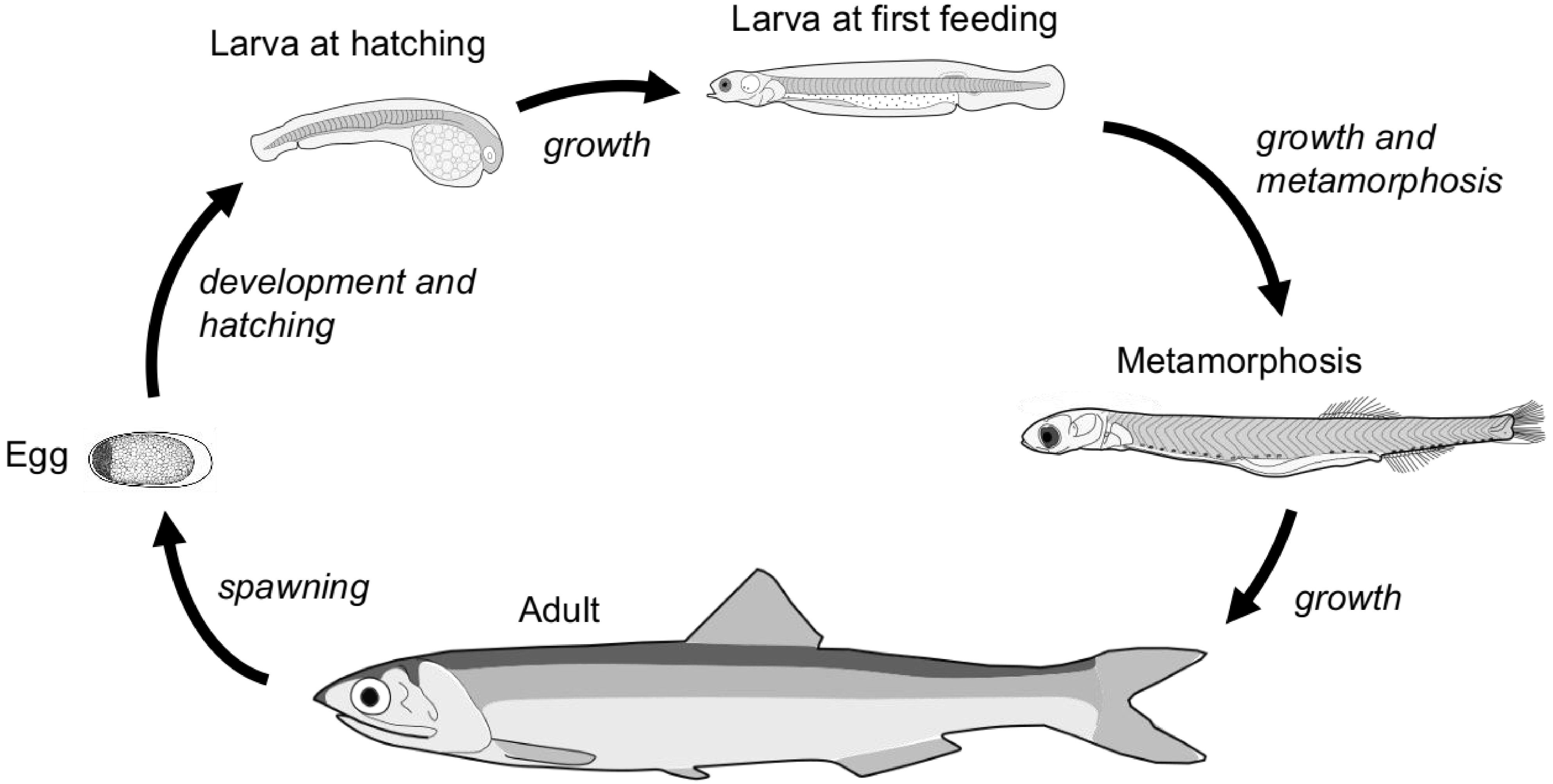


$$V = L^3 = \delta^3 \, L_{obs}^3$$

δ = shape coefficient

Introduction

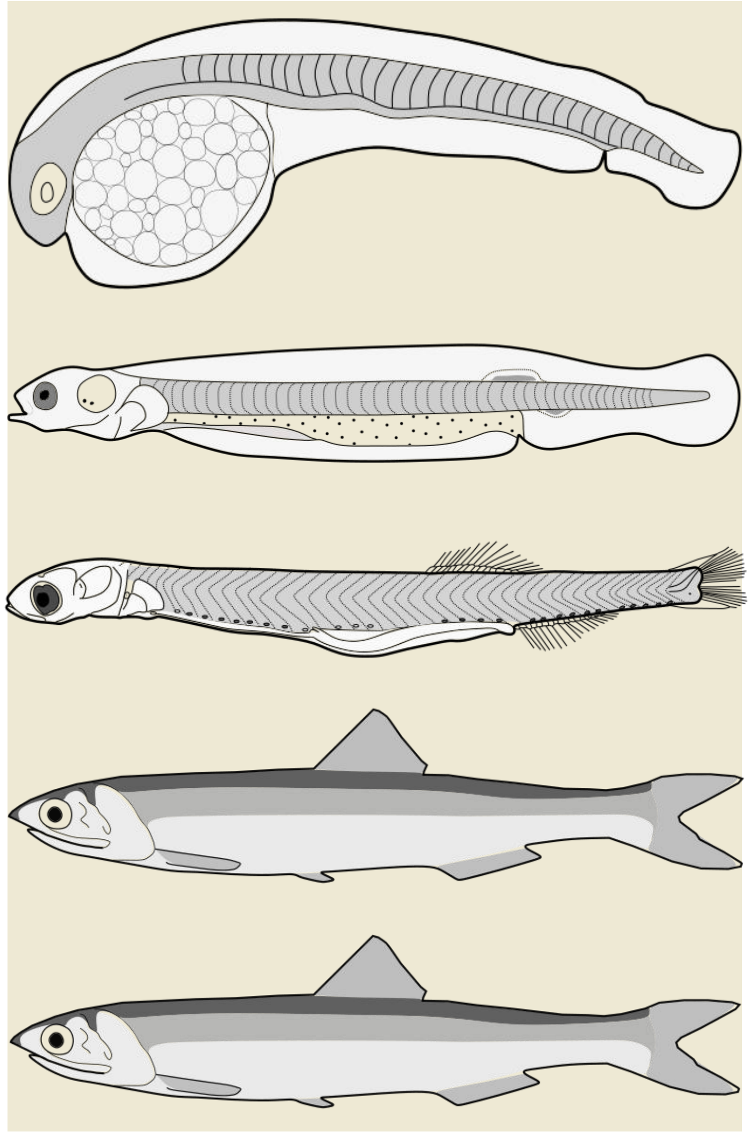
SPF morphology



adapted from Olivar and Fortuno (1991)

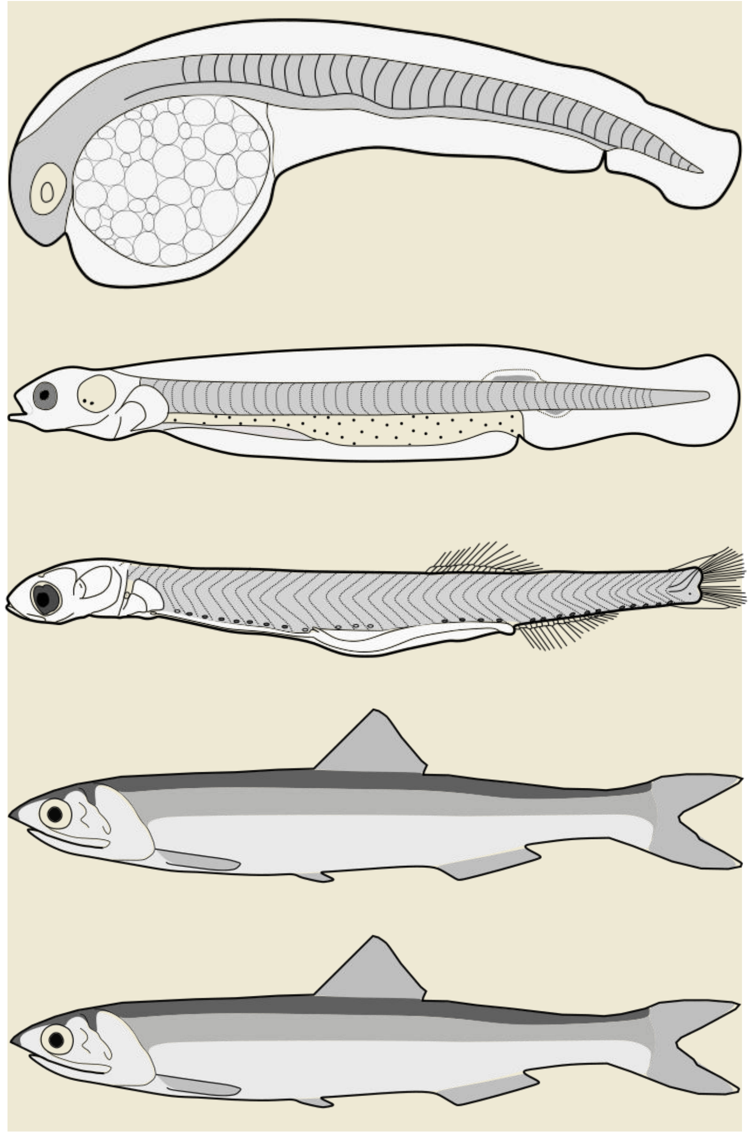
Introduction

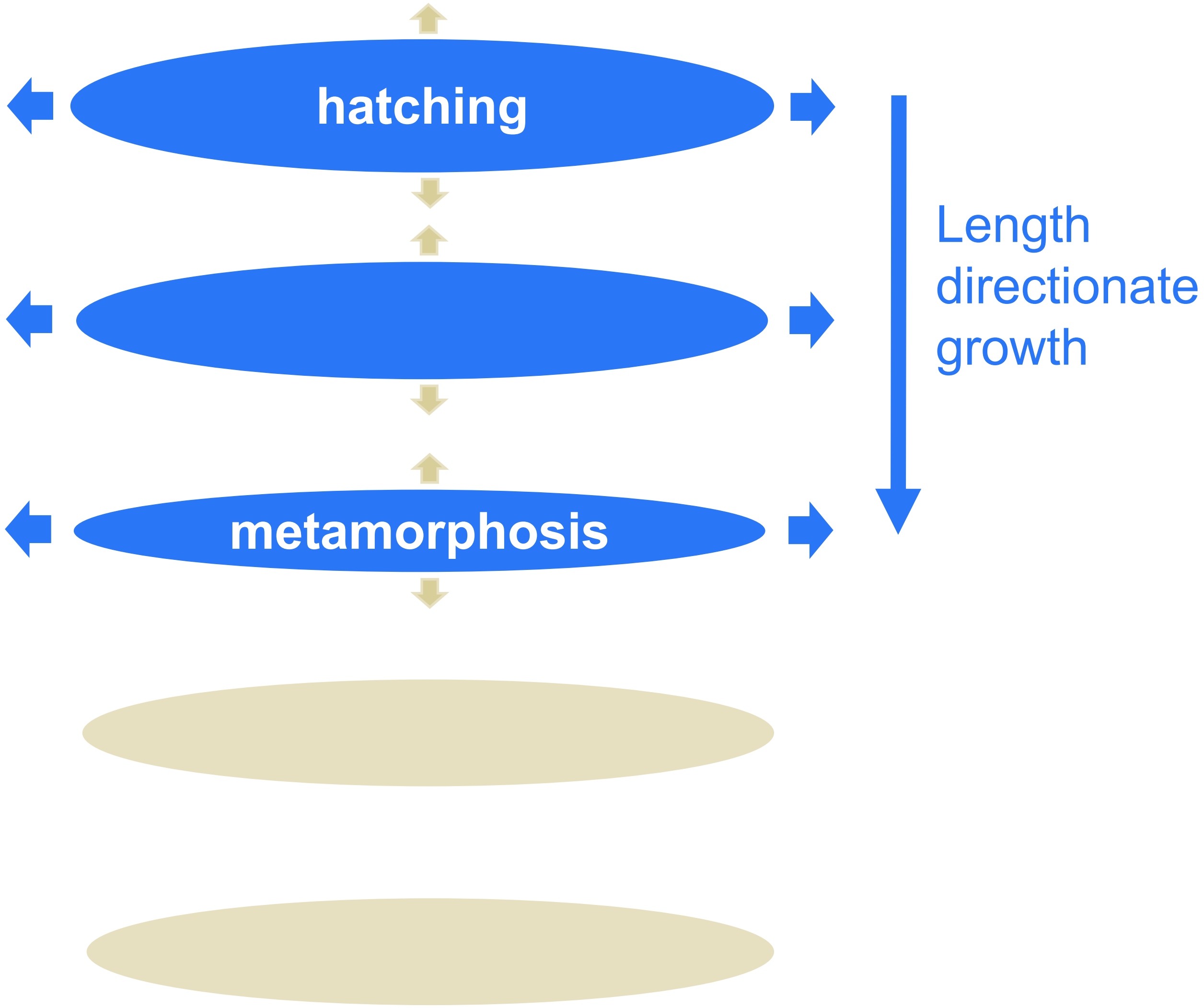
SPF morphology



Introduction

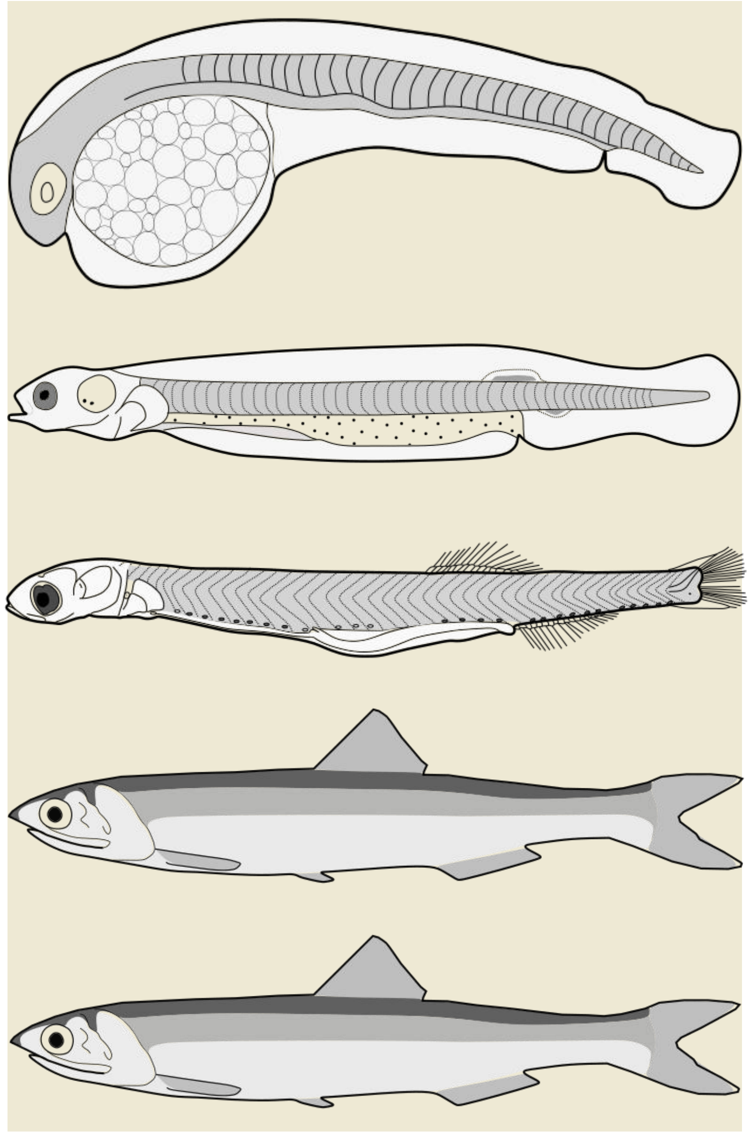
SPF morphology

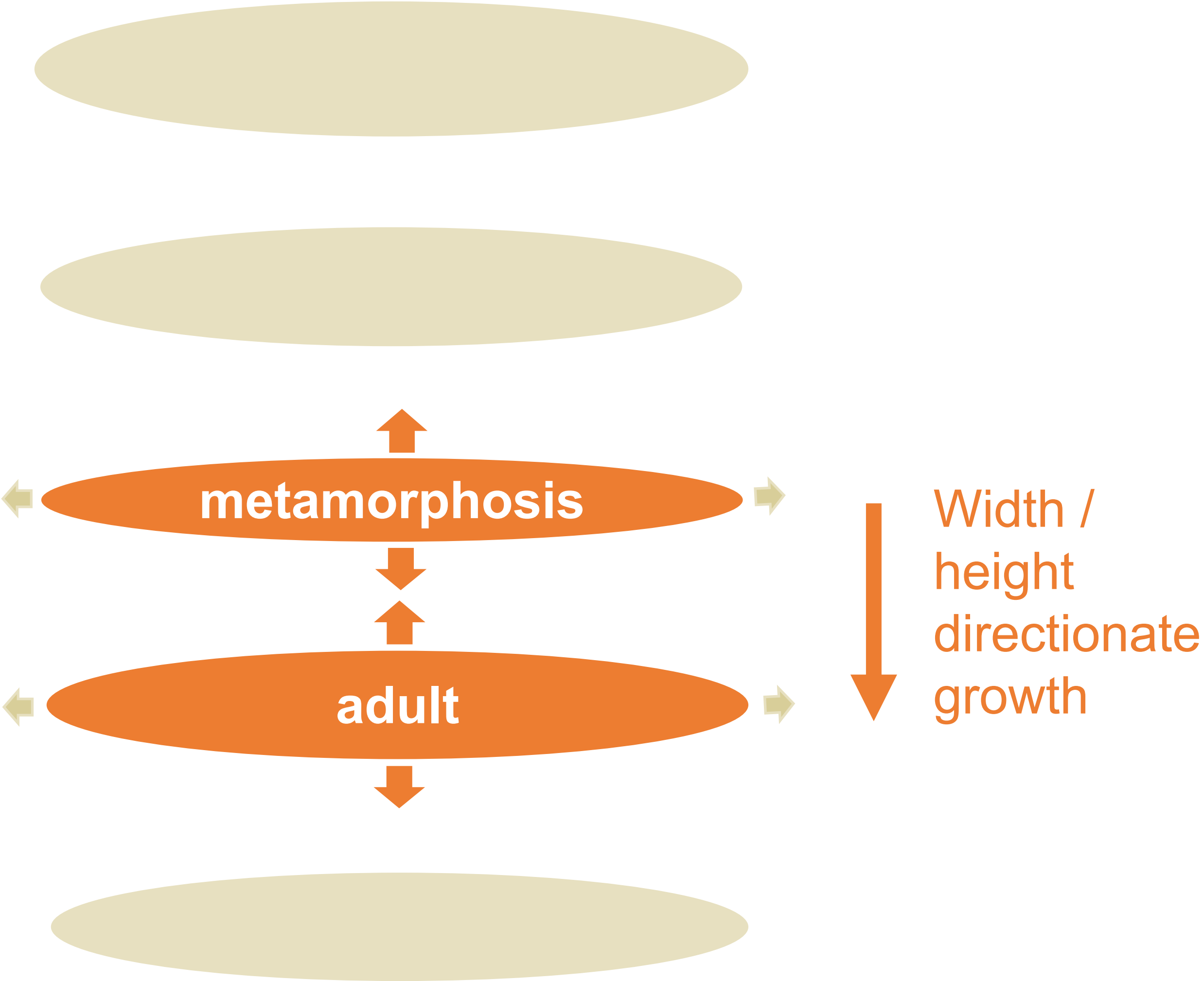




Introduction

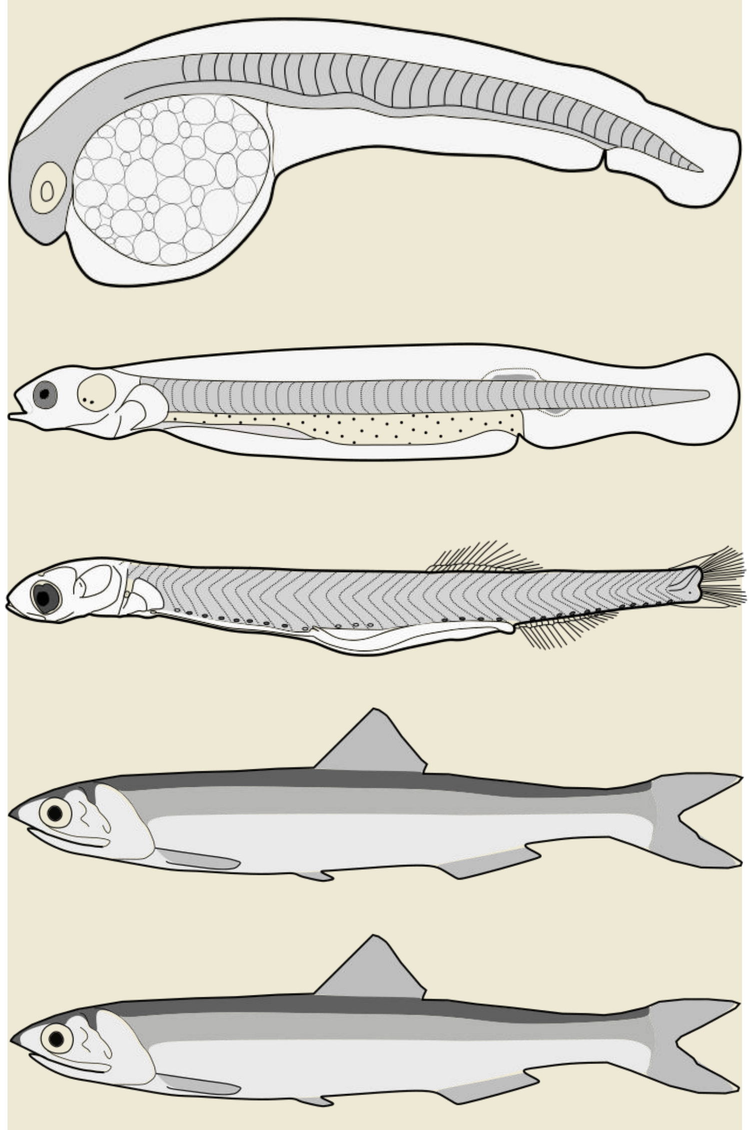
SPF morphology

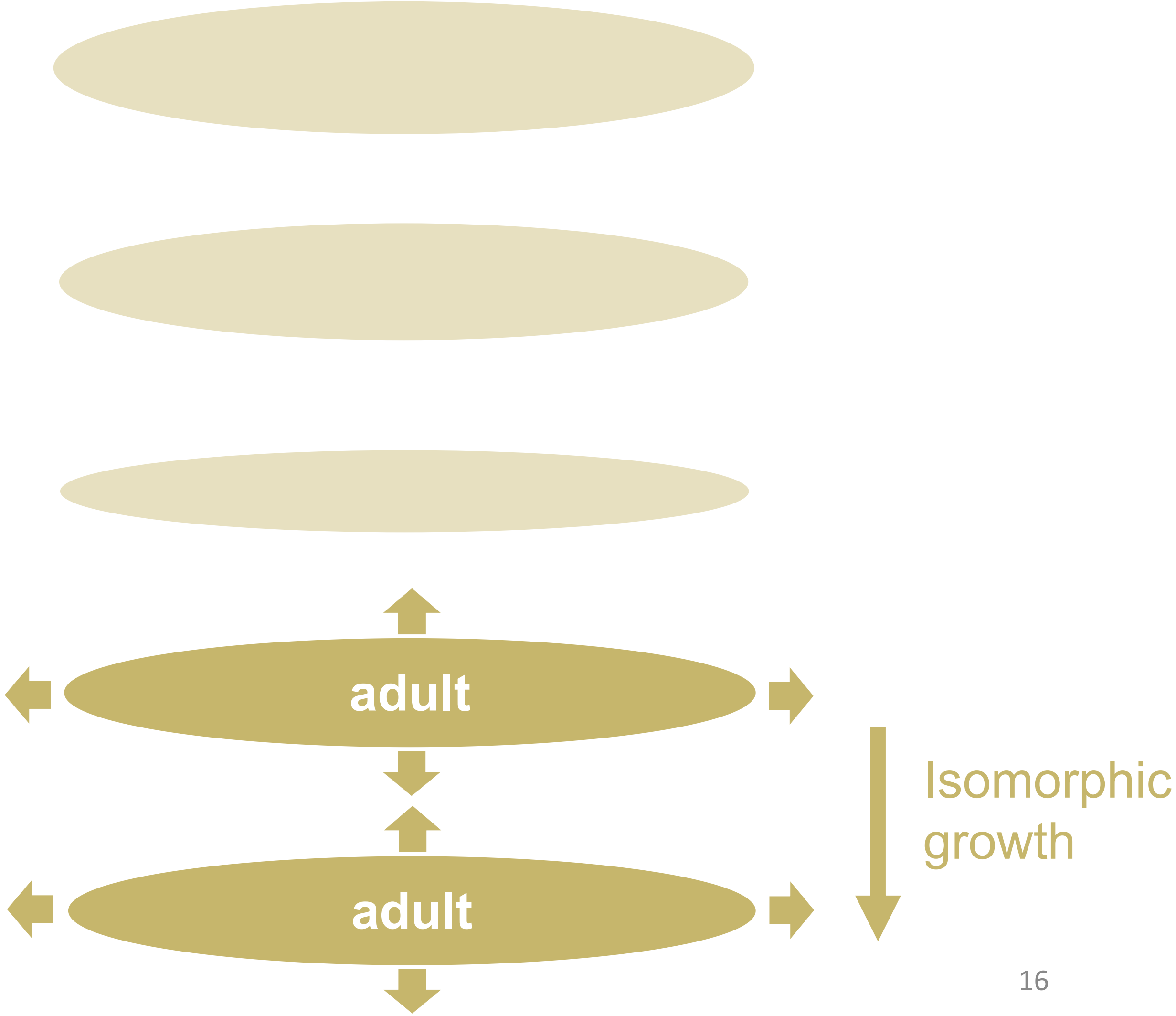




Introduction

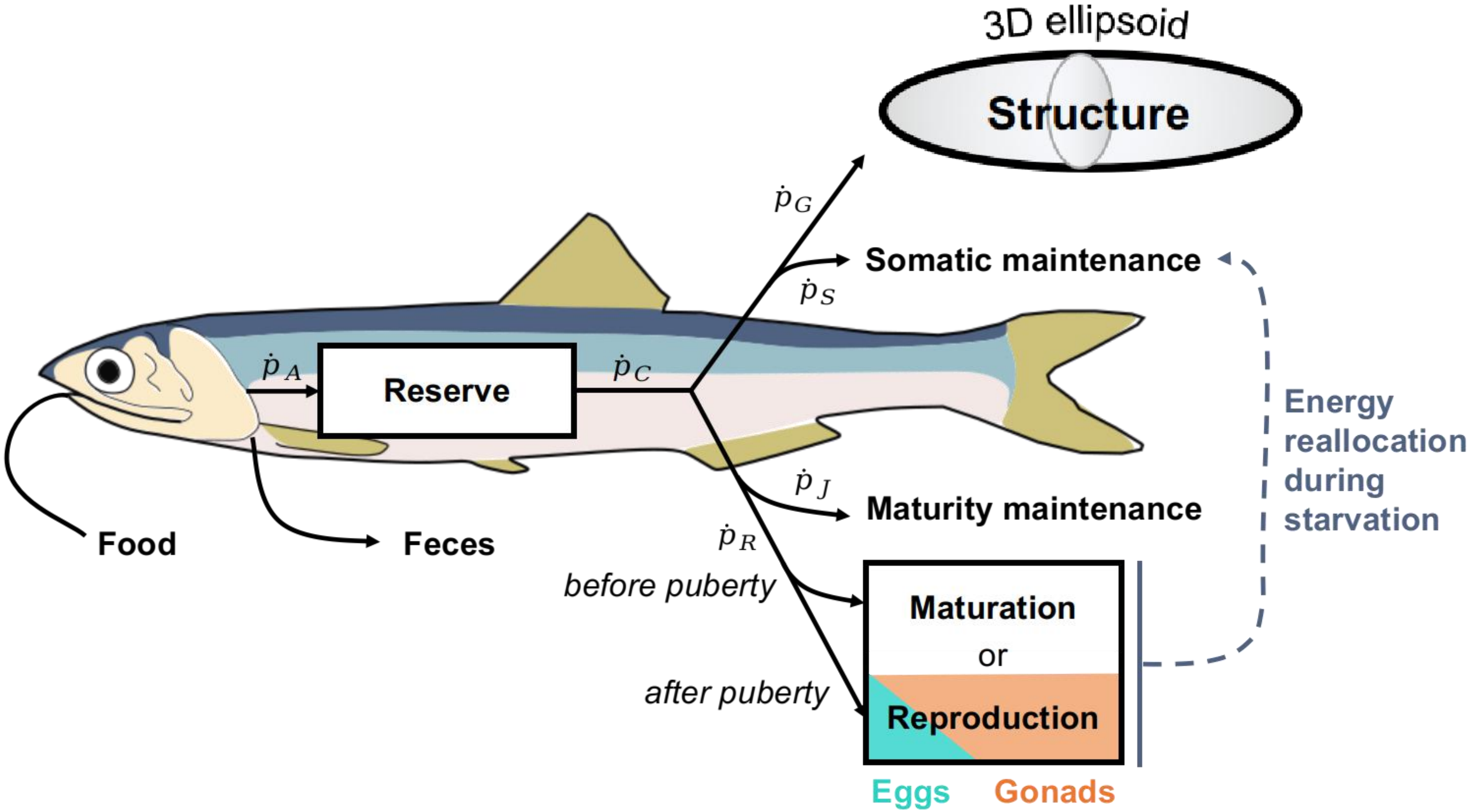
SPF morphology





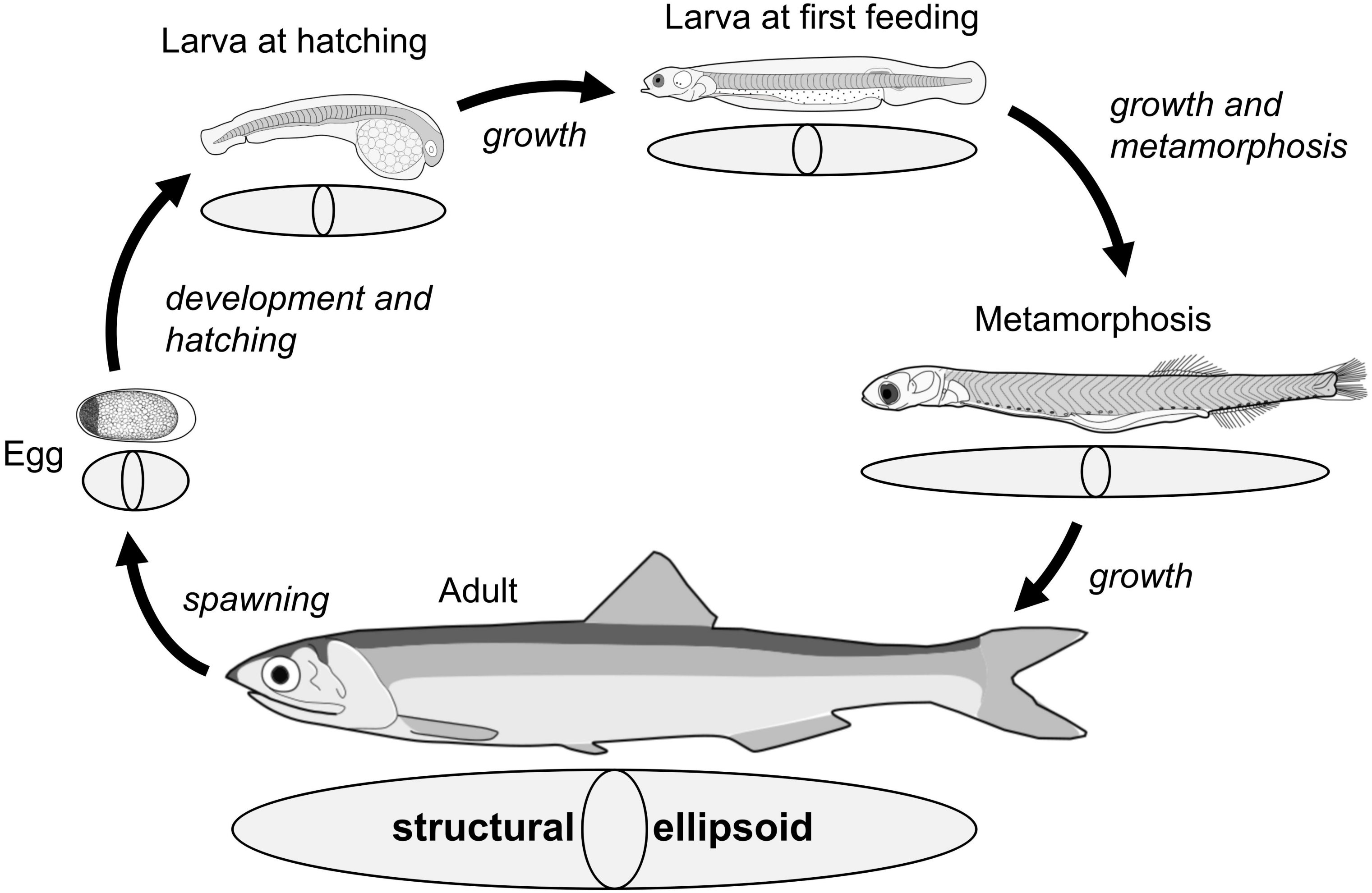
Methods

Generalized DEB model

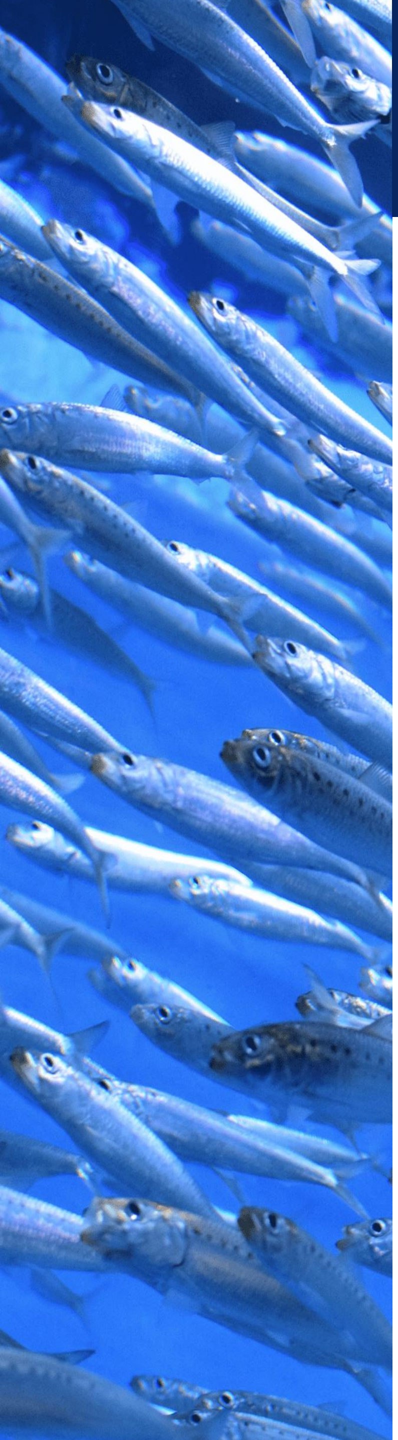


Methods

Life cycle and shape changes

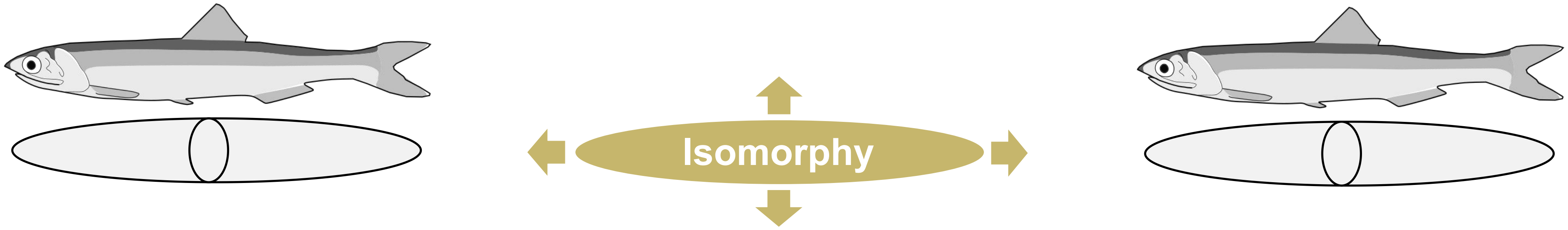


$$V = \frac{\pi}{6} \,.\, Width \,.\, Height \,.\, Length$$



Methods

Growth types



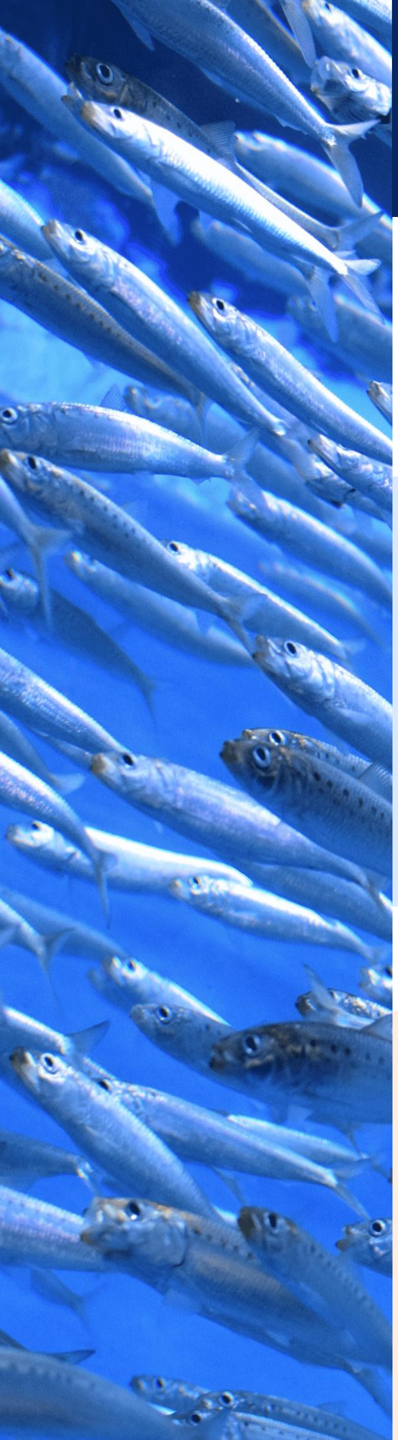
$$\frac{H_e}{L_e} = h_e\ (constant) \qquad \frac{W_e}{L_e} = w_e\ (constant)$$

+ simplification : $\frac{H_e}{W_e} = constant$

$$V = \frac{\pi}{6}\, h_e\, w_e\, L_e^{3}$$

$$\frac{dV}{dt} = \frac{\pi}{6}\, h_e\, w_e\, 3\, L_e^{2} \left(\frac{dL_e}{dt}\right)_i$$

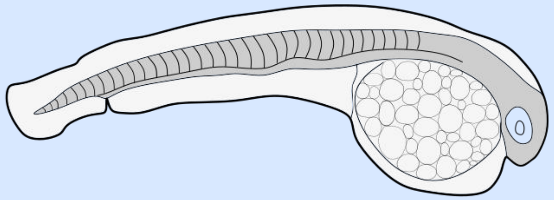
$$\left(\frac{dL_e}{dt}\right)_i = \frac{2}{\pi\, H_e\, W_e}\, \frac{dV}{dt}$$

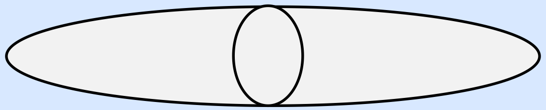


Methods

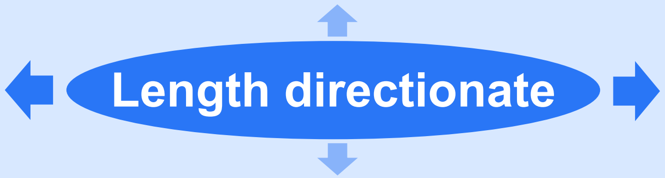
Growth types

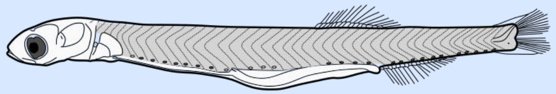
$$\frac{dV}{dt} = \frac{\pi}{6}\left(H_e\, L_e \frac{dW_e}{dt} + W_e\, L_e \frac{dH_e}{dt} + W_e\, H_e \frac{dL_e}{dt}\right)$$



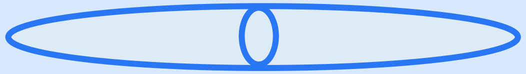


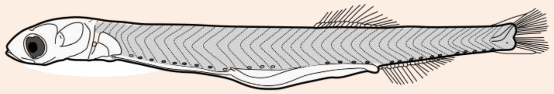
$$\left(\frac{dL_e}{dt}\right)_i \leq \frac{dL_e}{dt} \leq \left(\frac{dL_e}{dt}\right)_m$$

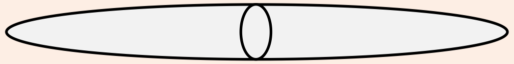




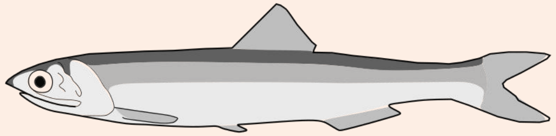
attractor



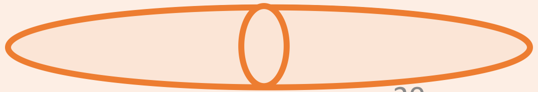


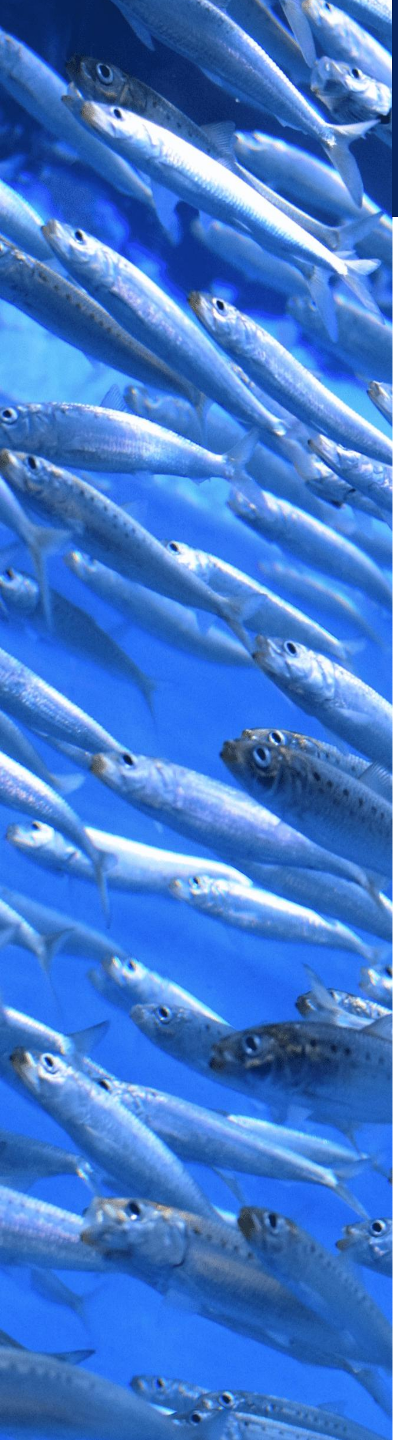


$$\left(\frac{dH_e}{dt}\right)_i \leq \frac{dH_e}{dt} \leq \left(\frac{dH_e}{dt}\right)_m$$



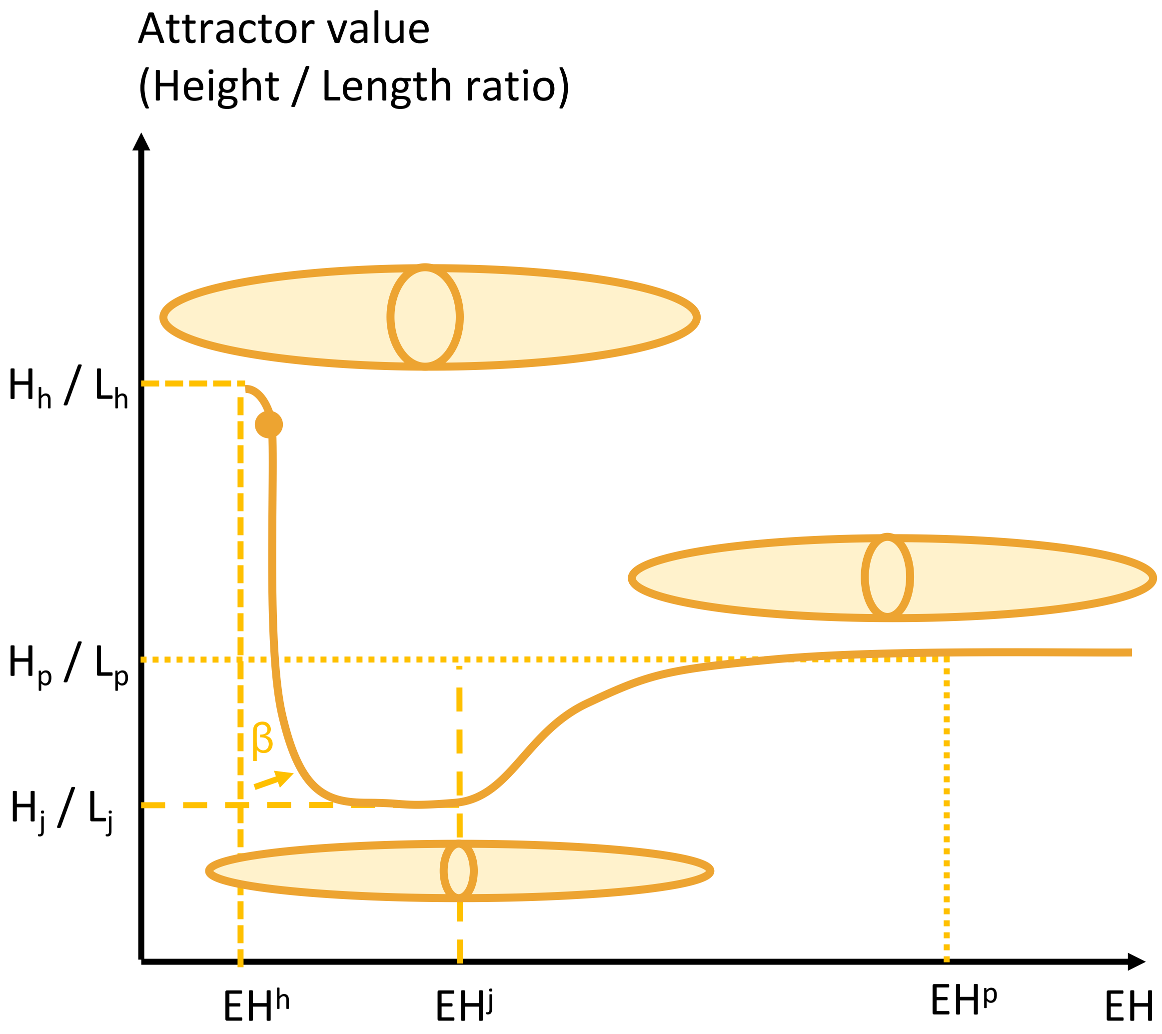
attractor





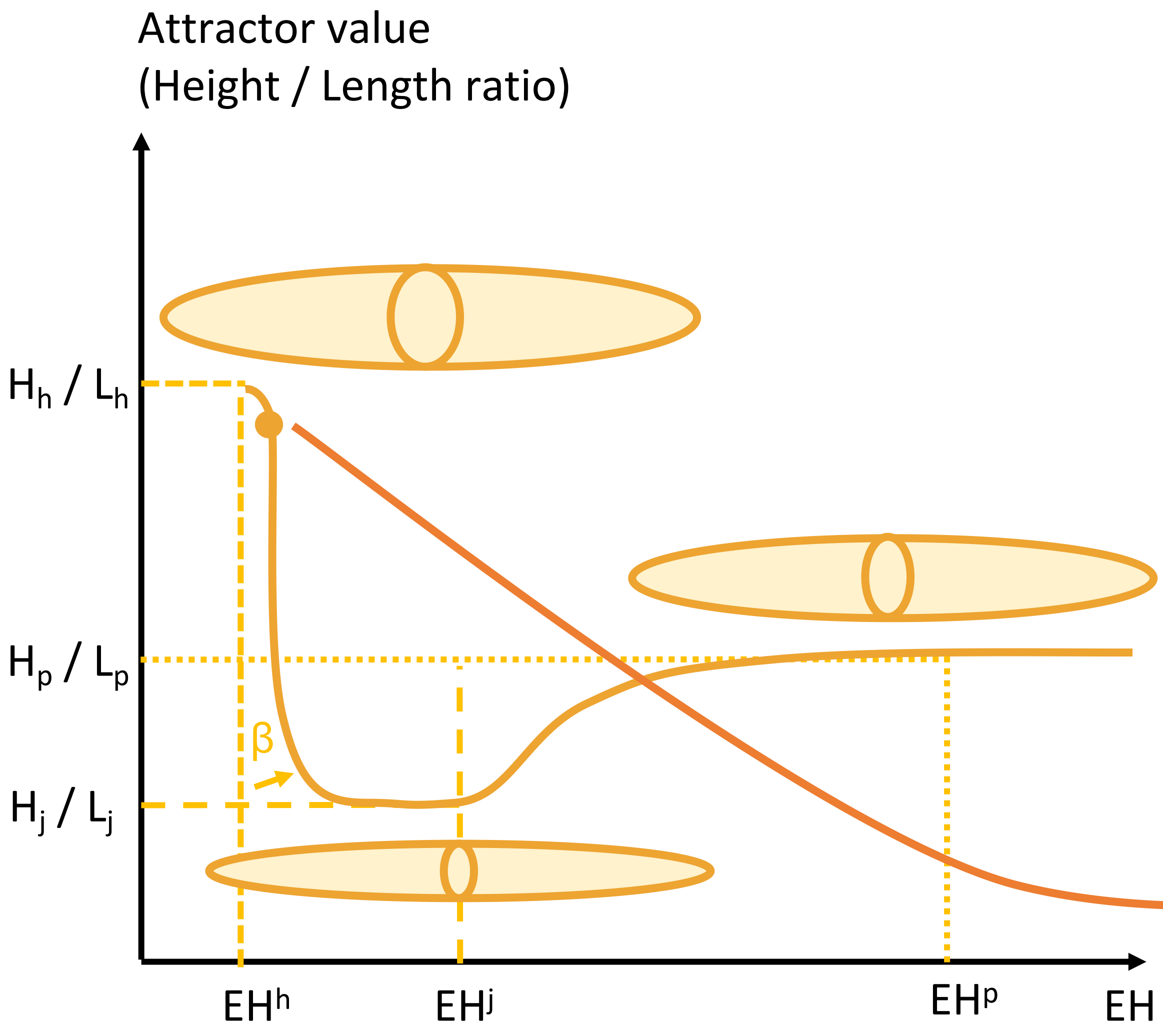
Methods

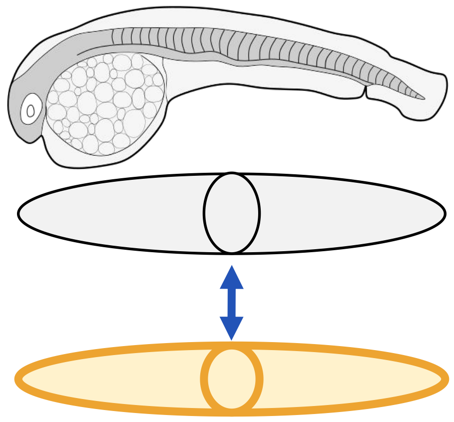
$$\left(\frac{dL_e}{dt}\right)_i \leq \frac{dL_e}{dt} \leq \left(\frac{dL_e}{dt}\right)_m \qquad \left(\frac{dH_e}{dt}\right)_i \leq \frac{dH_e}{dt} \leq \left(\frac{dH_e}{dt}\right)_m$$

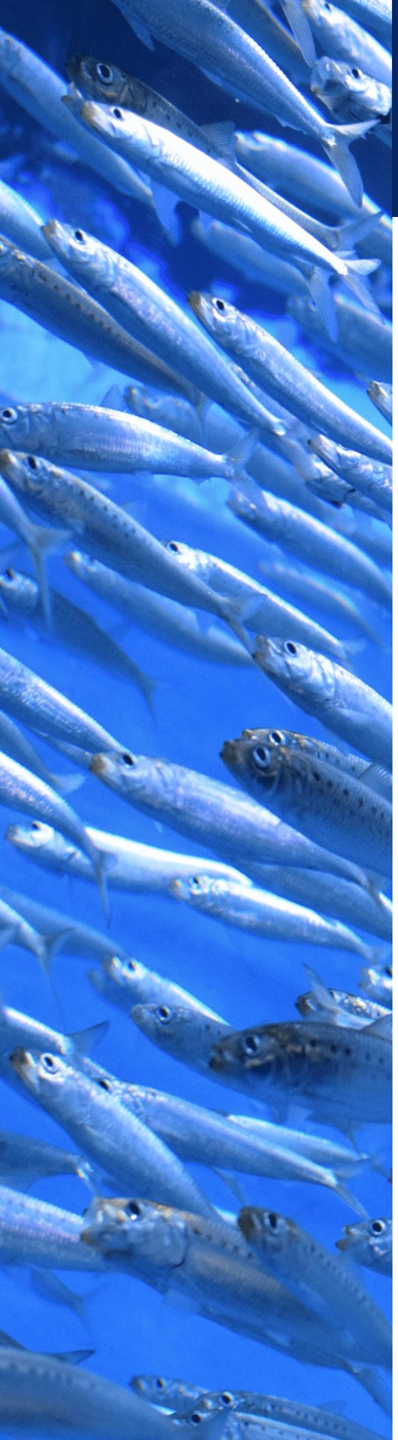


Methods

$$\left(\frac{dL_e}{dt}\right)_i \leq \frac{dL_e}{dt} \leq \left(\frac{dL_e}{dt}\right)_m \qquad \left(\frac{dH_e}{dt}\right)_i \leq \frac{dH_e}{dt} \leq \left(\frac{dH_e}{dt}\right)_m$$

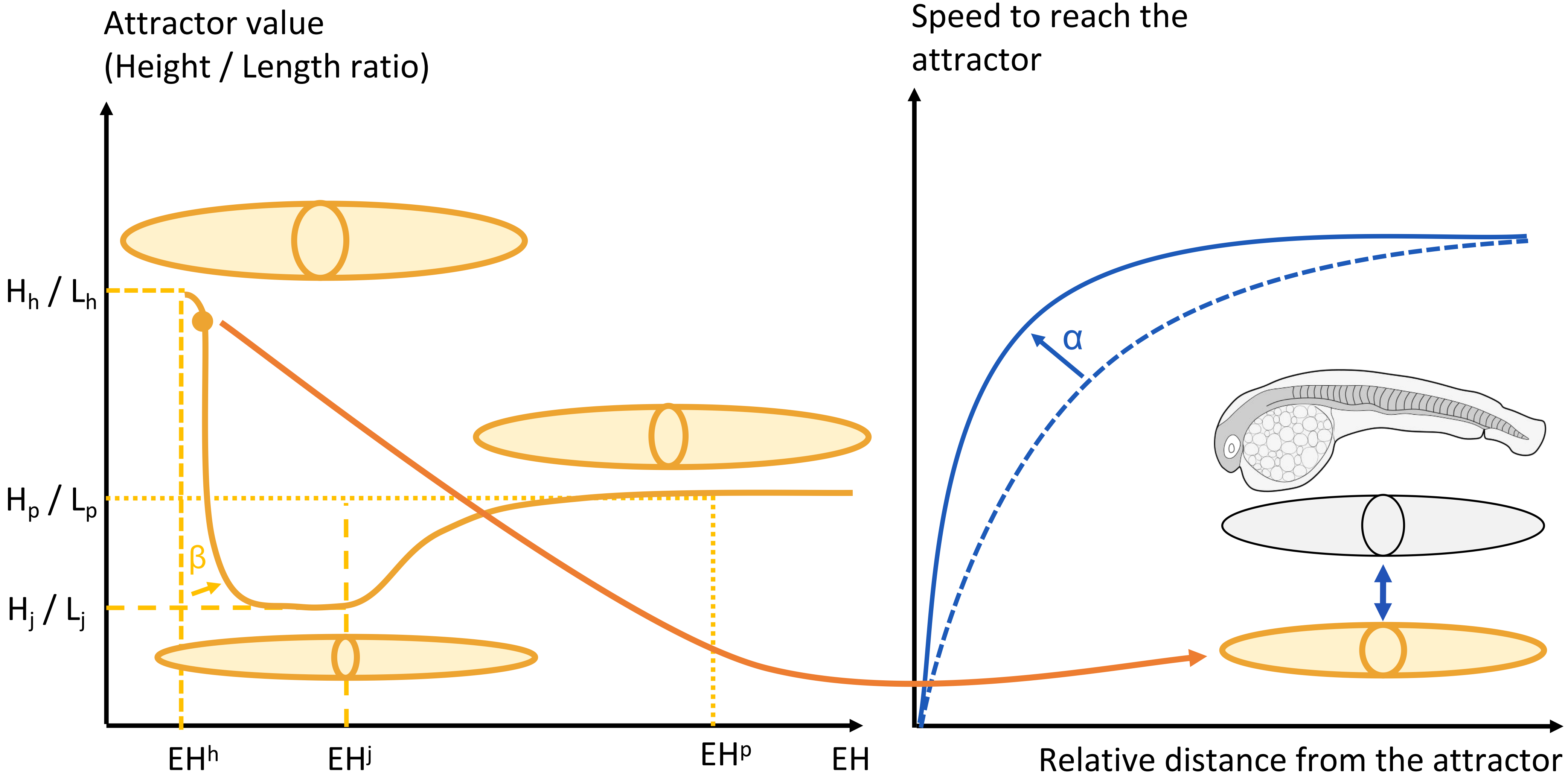




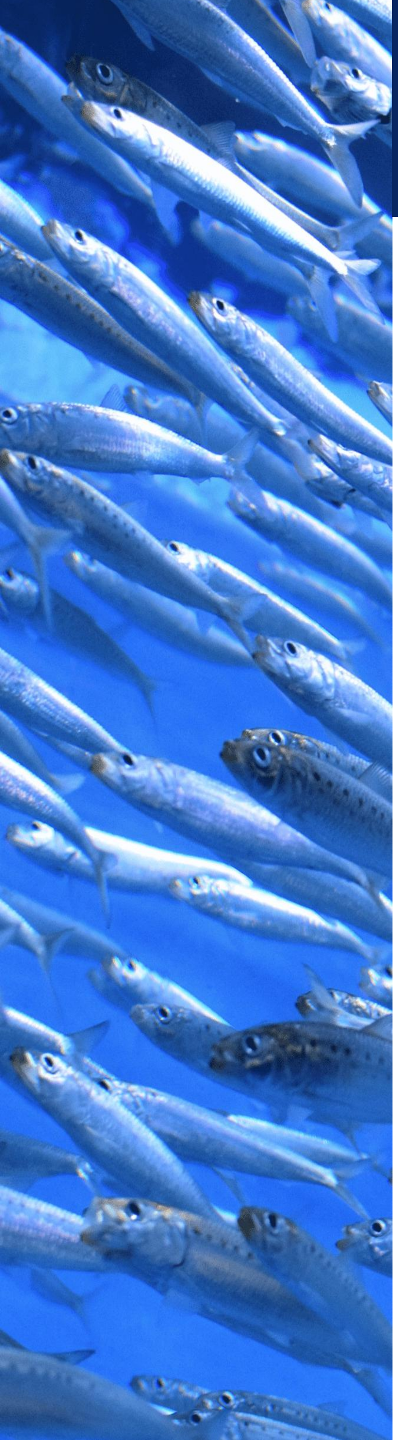


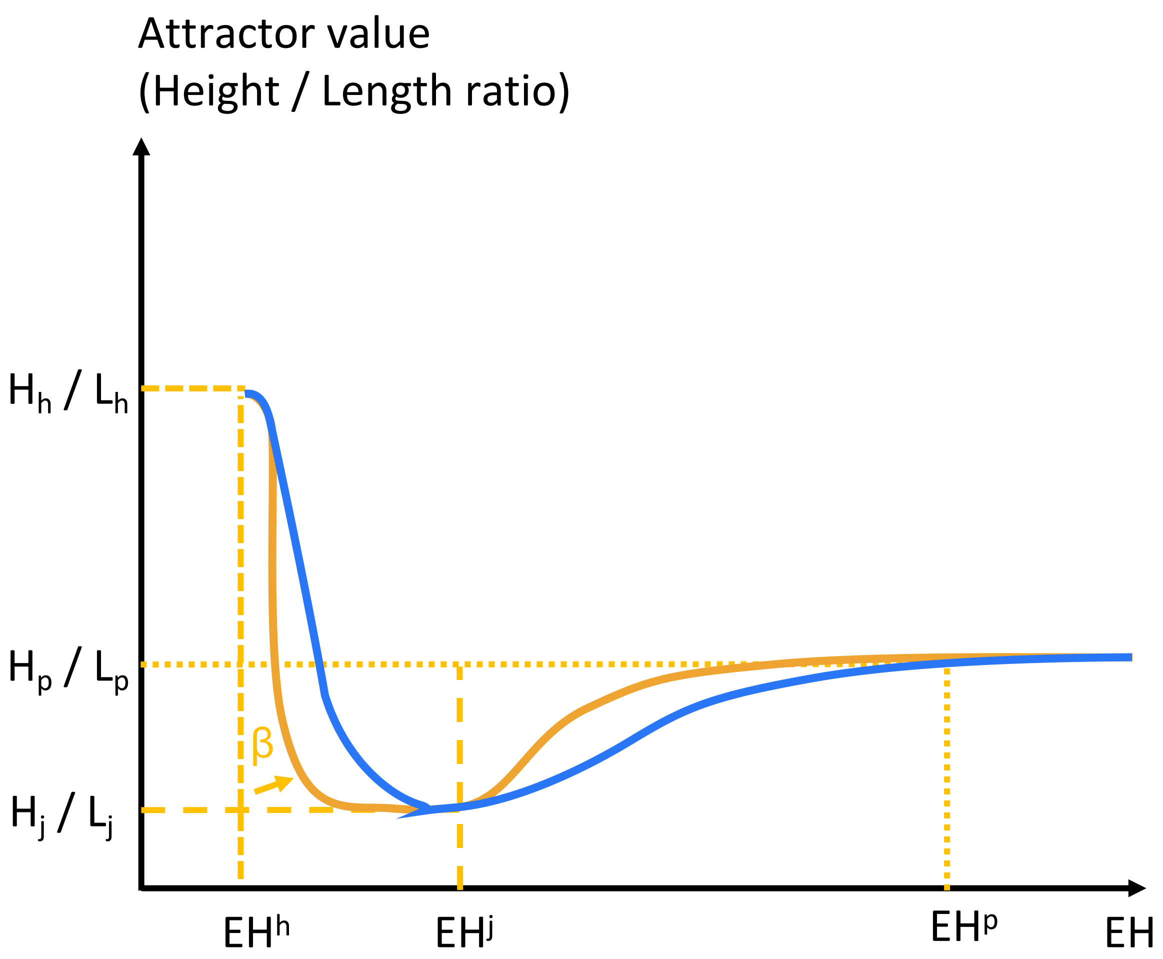
Methods

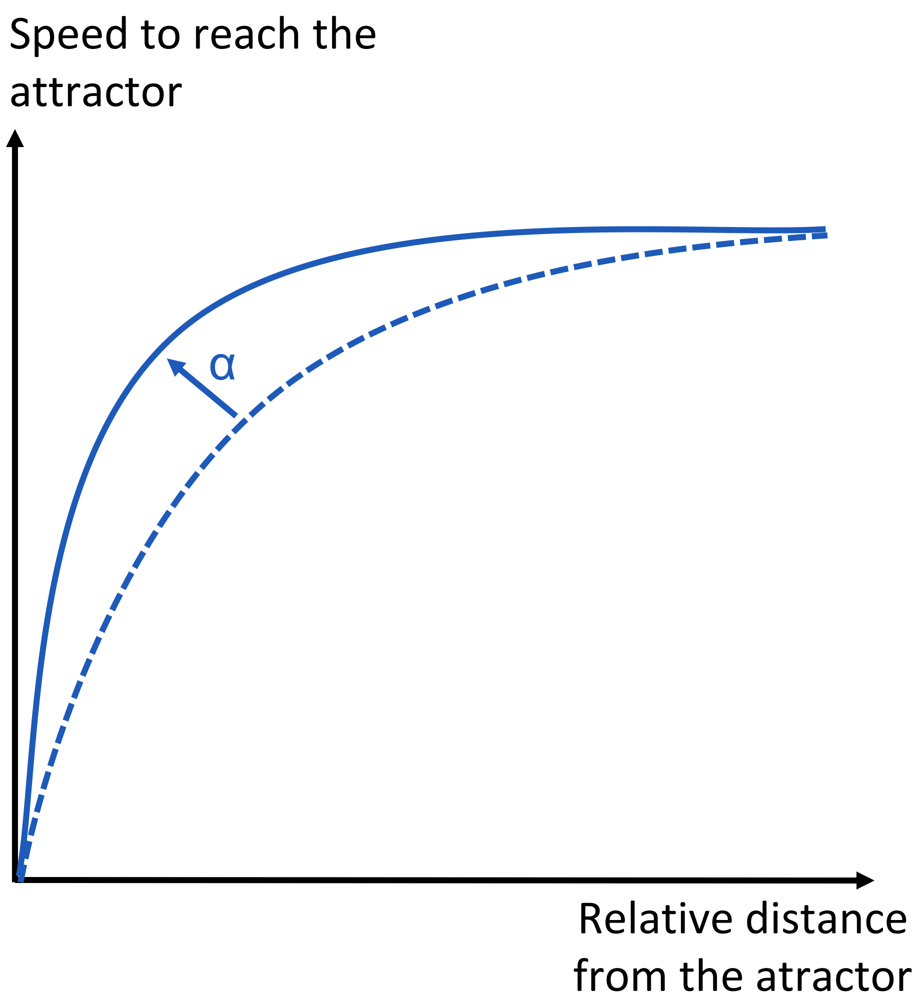
$$\left(\frac{dL_e}{dt}\right)_i \leq \frac{dL_e}{dt} \leq \left(\frac{dL_e}{dt}\right)_m \qquad \left(\frac{dH_e}{dt}\right)_i \leq \frac{dH_e}{dt} \leq \left(\frac{dH_e}{dt}\right)_m$$

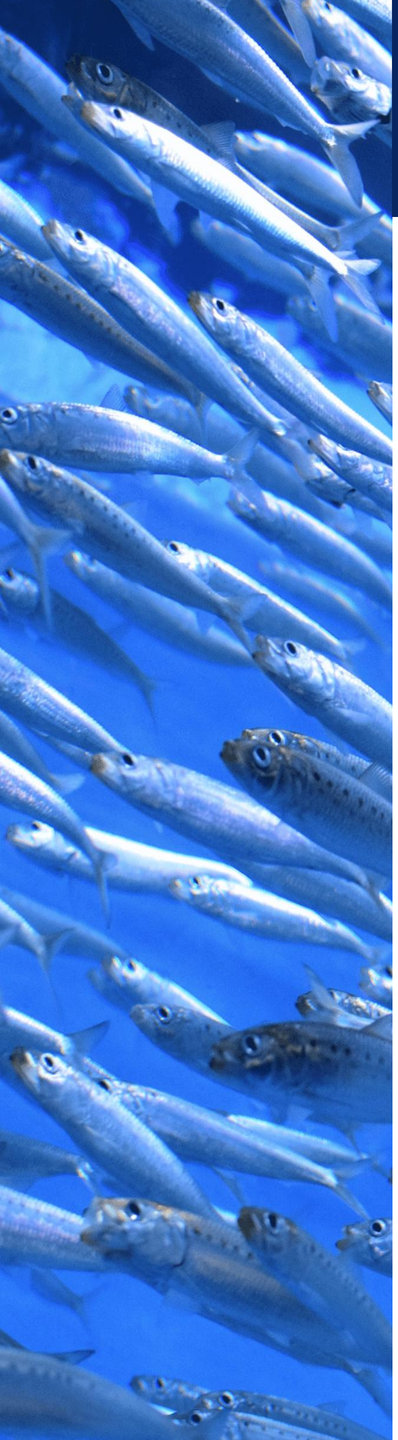


Methods



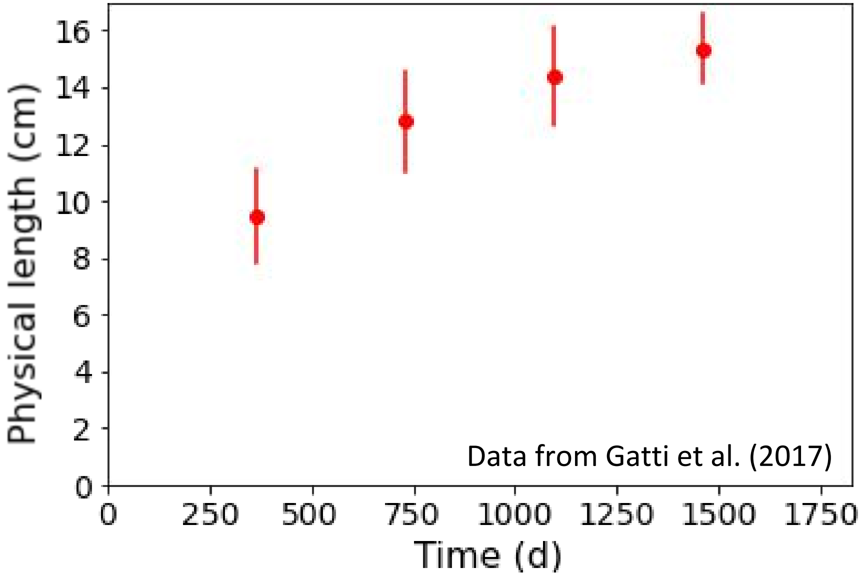

Attractor value
(Height / Length ratio)
H_h / L_h
H_p / L_p
β
H_j / L_j
EH^h
EH^j
EH^p
EH

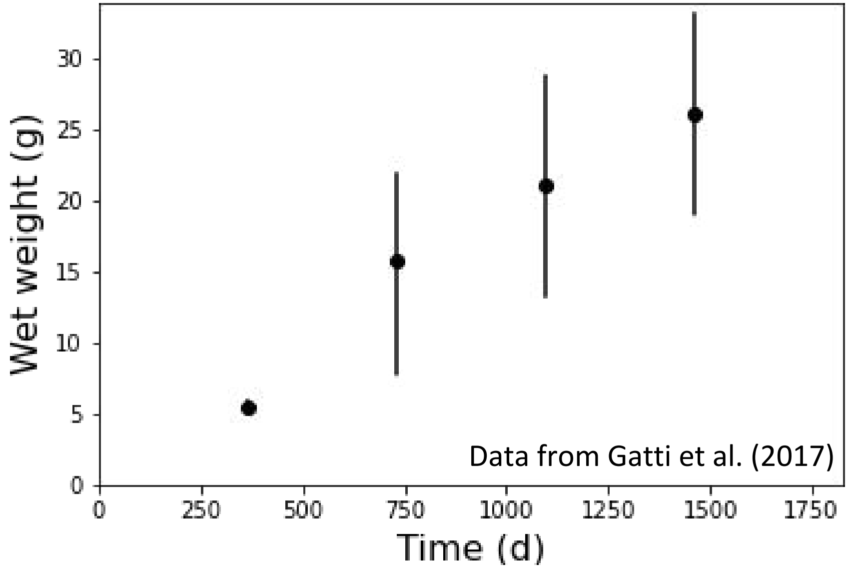

Speed to reach the attractor
α
Relative distance from the atractor

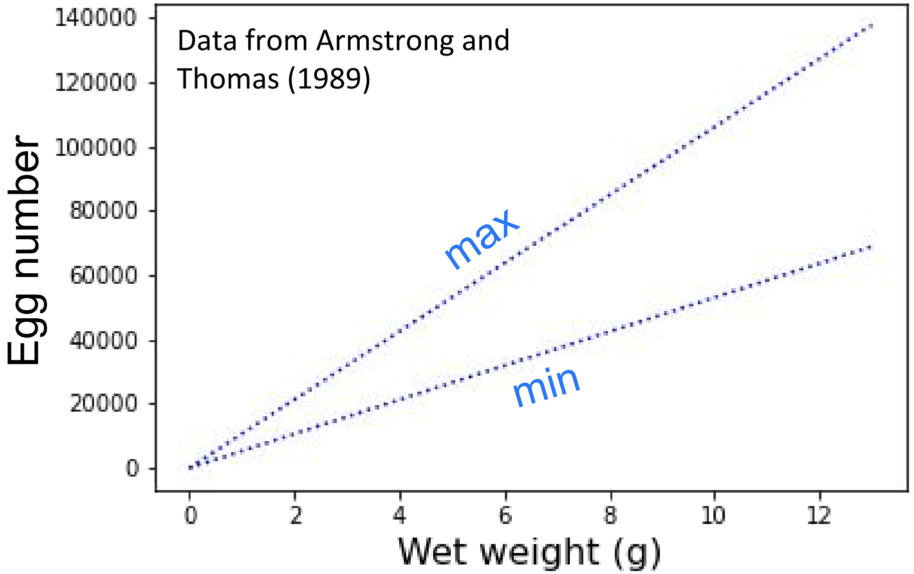


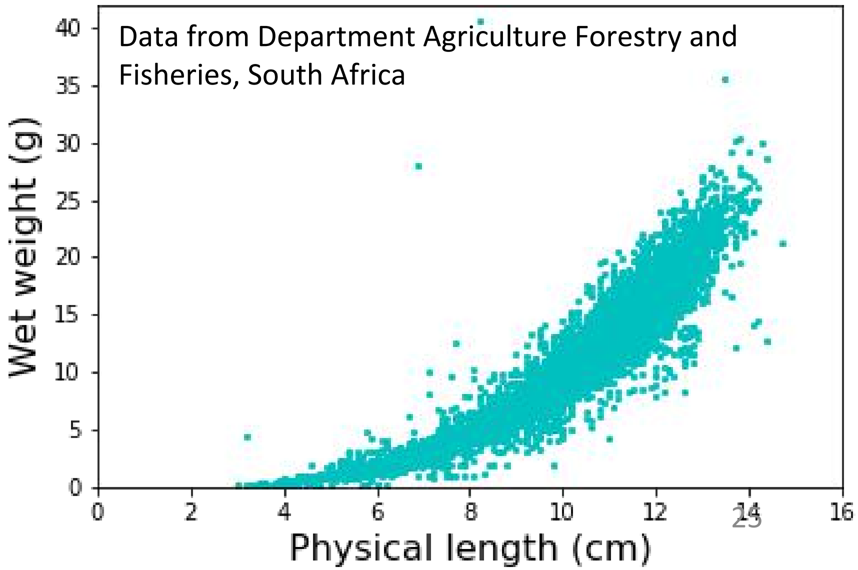
Results

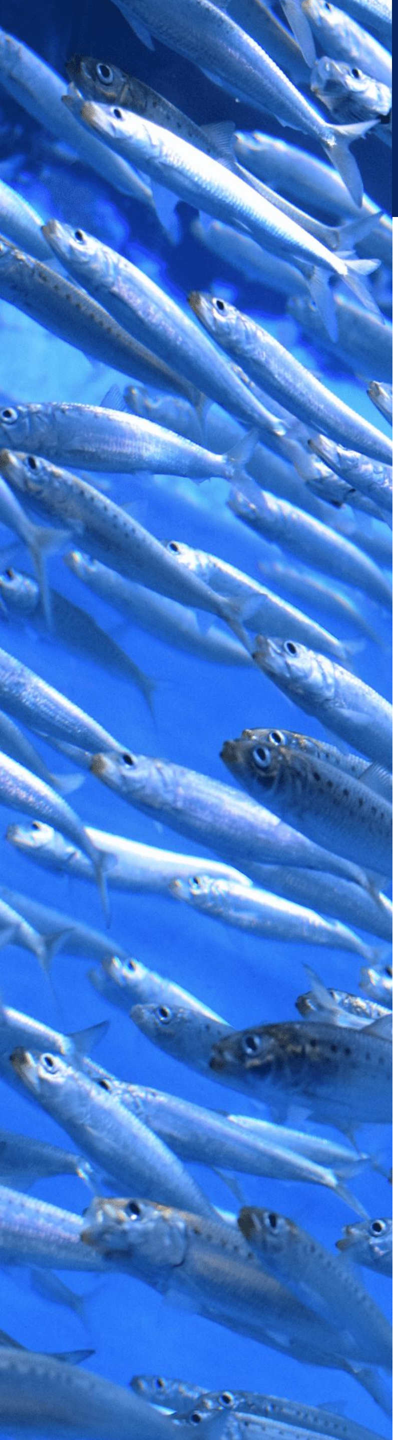
Model vs data - adult stage



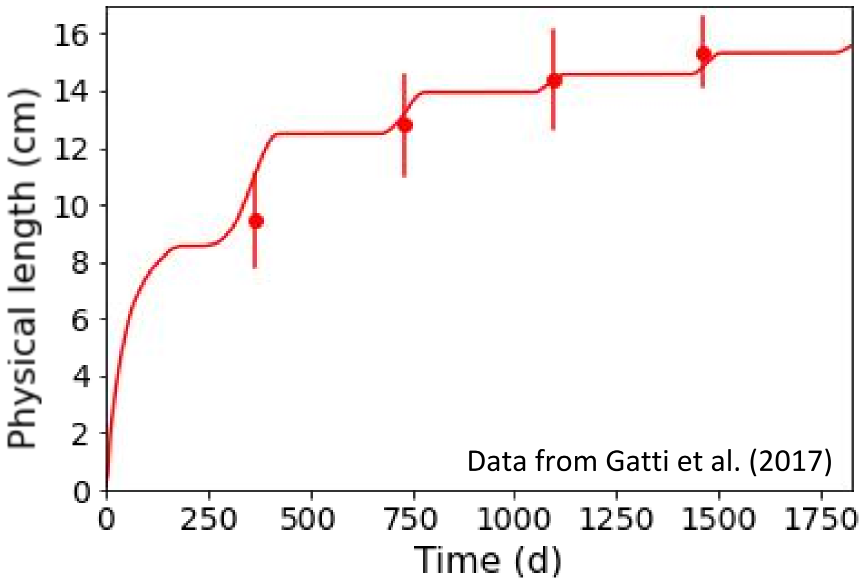


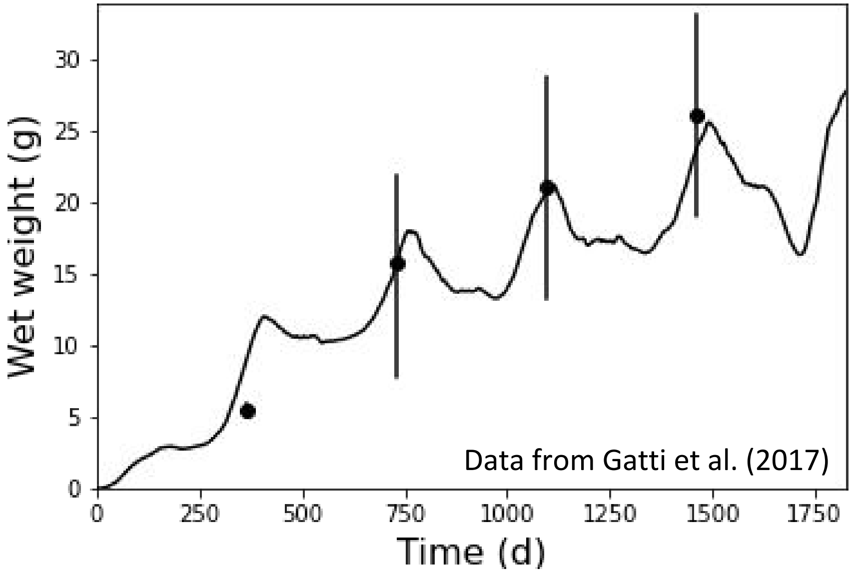


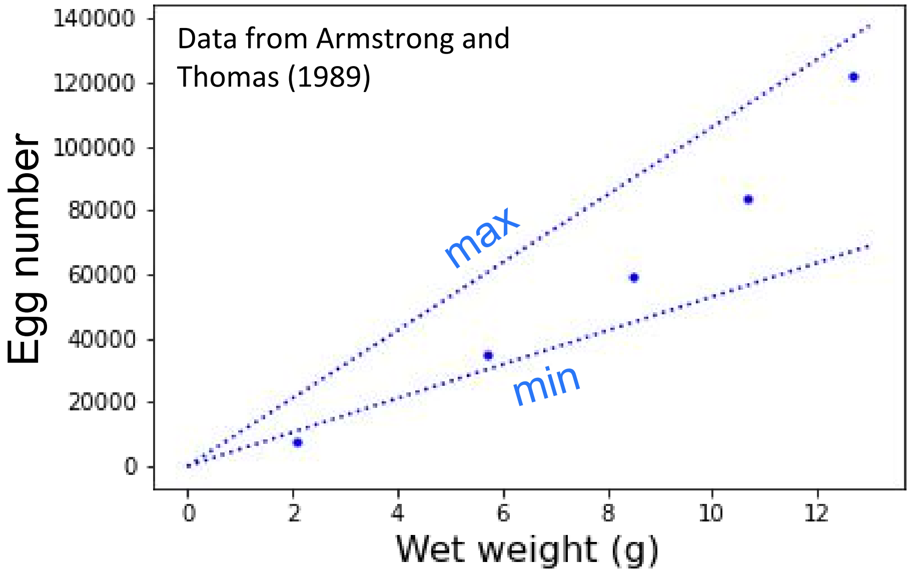


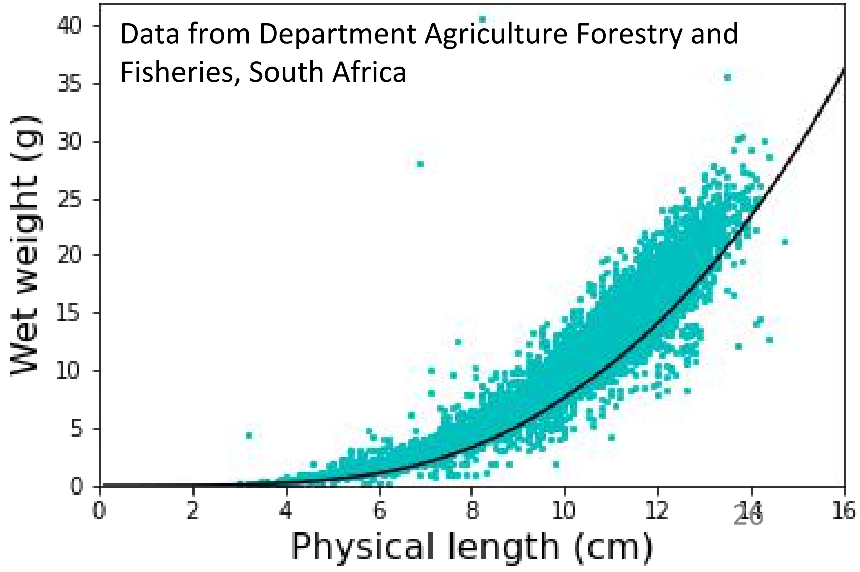


Results *Model vs data - adult stage*

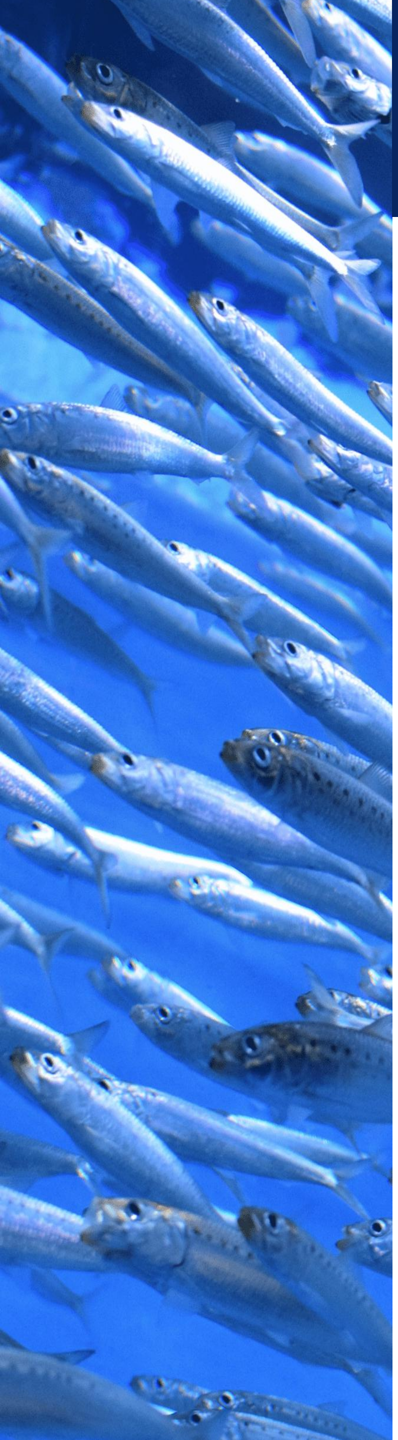


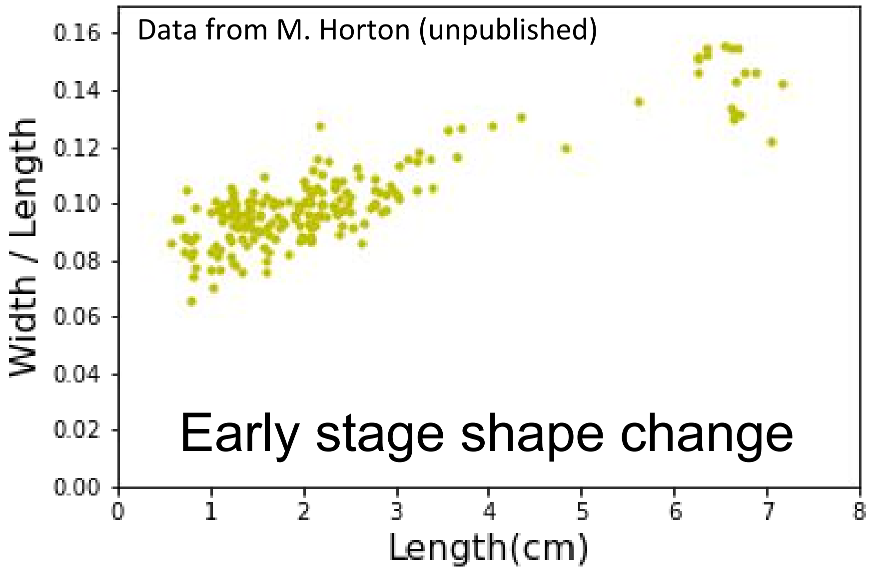


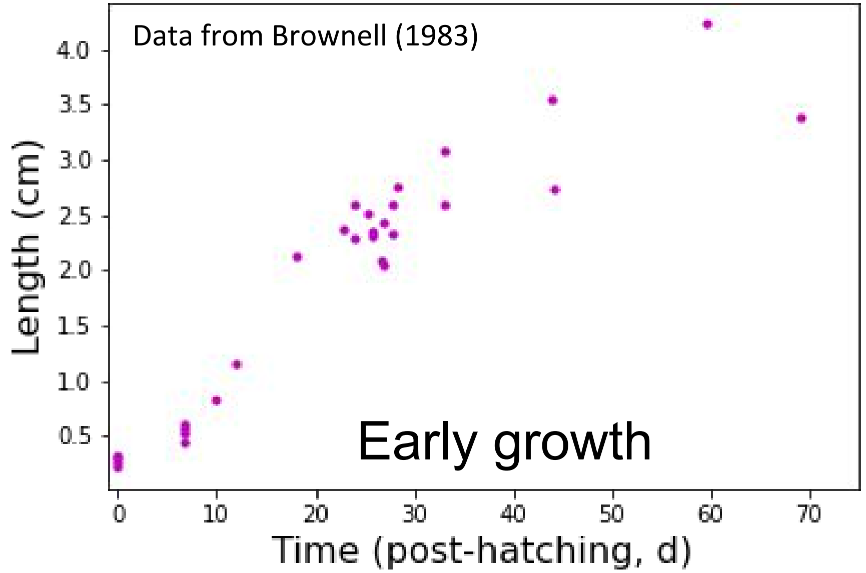


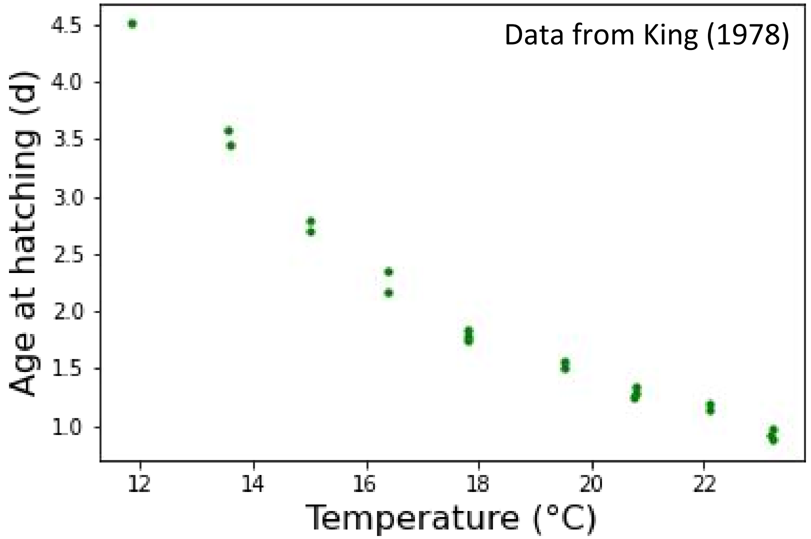


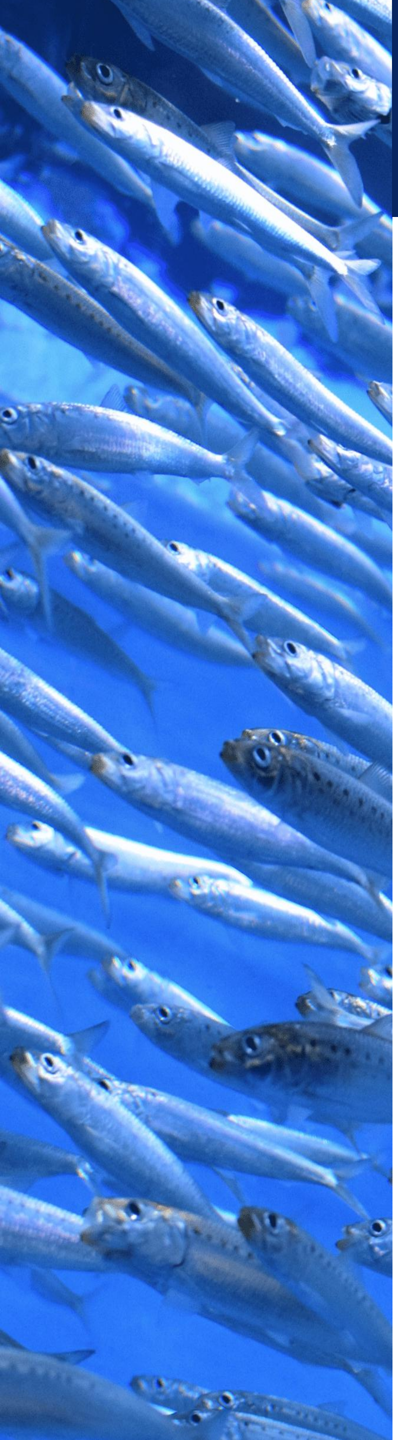
Results *Model vs data - early stages*











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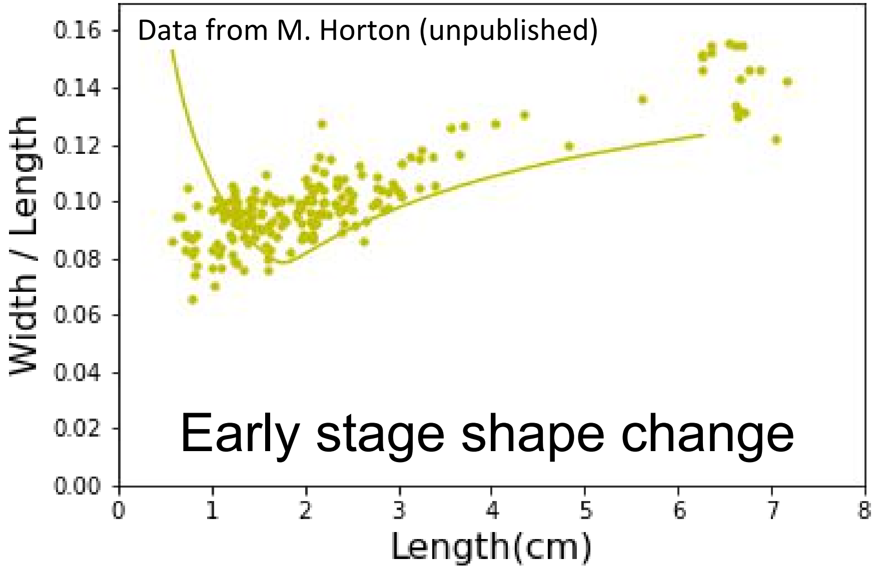
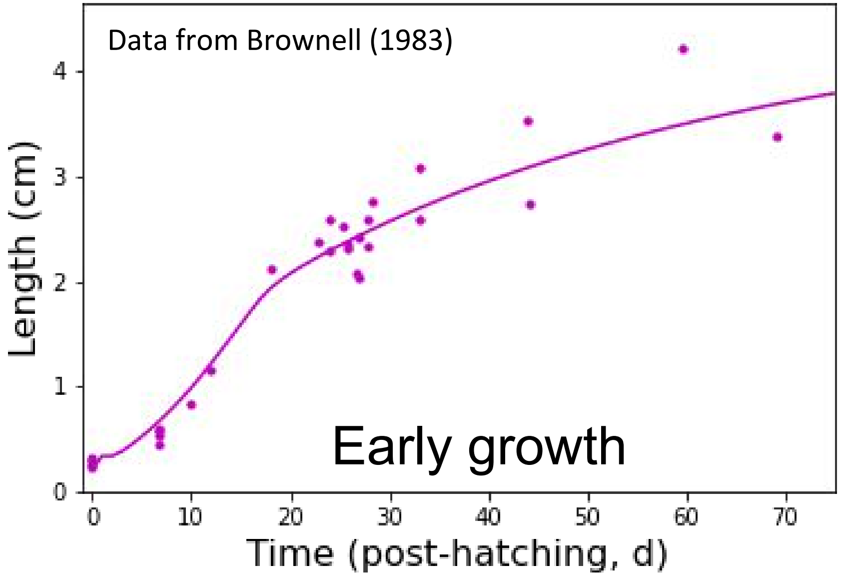
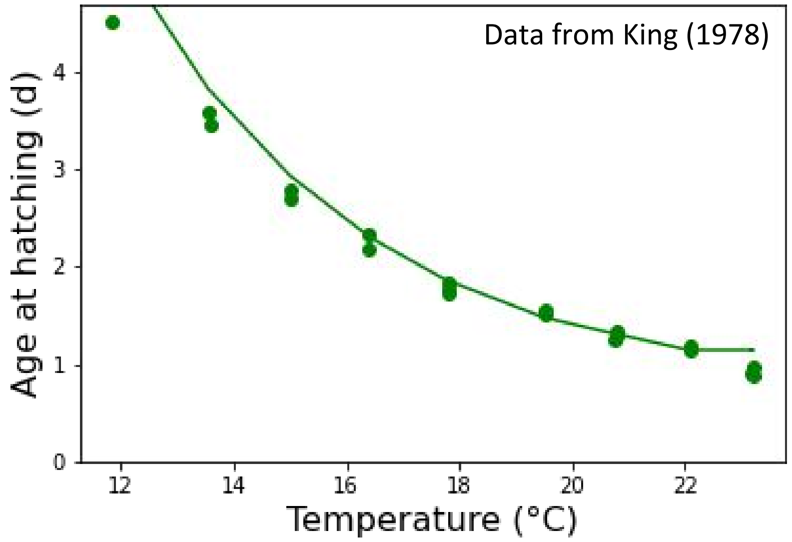
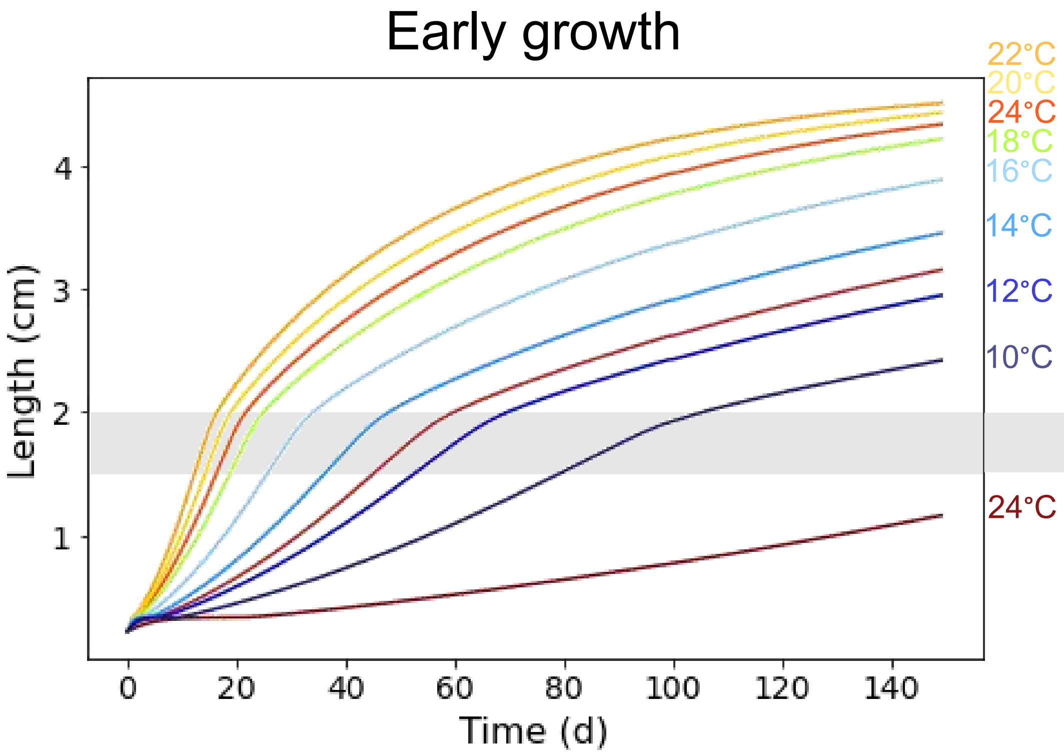




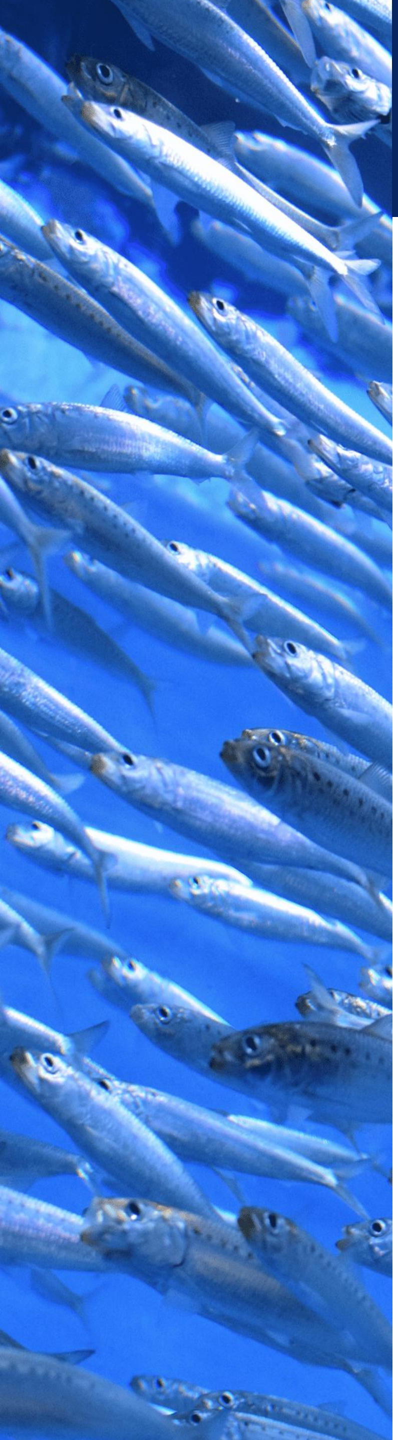


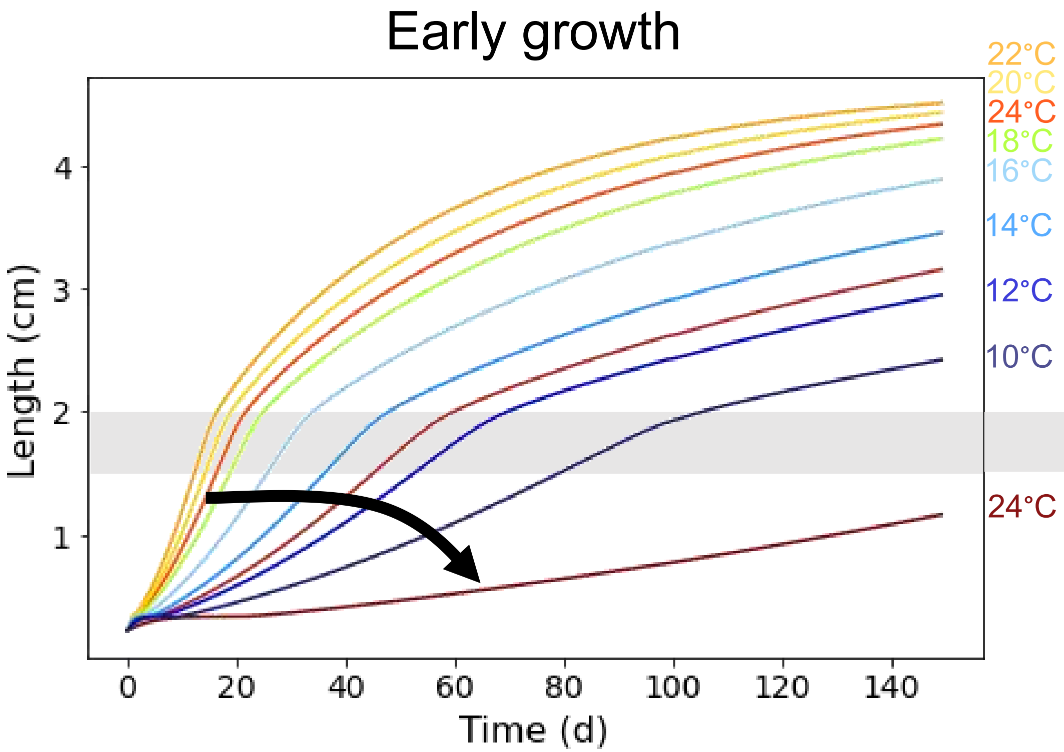
Results — *Temperature effect on growth*



Ability to escape the viscous drag

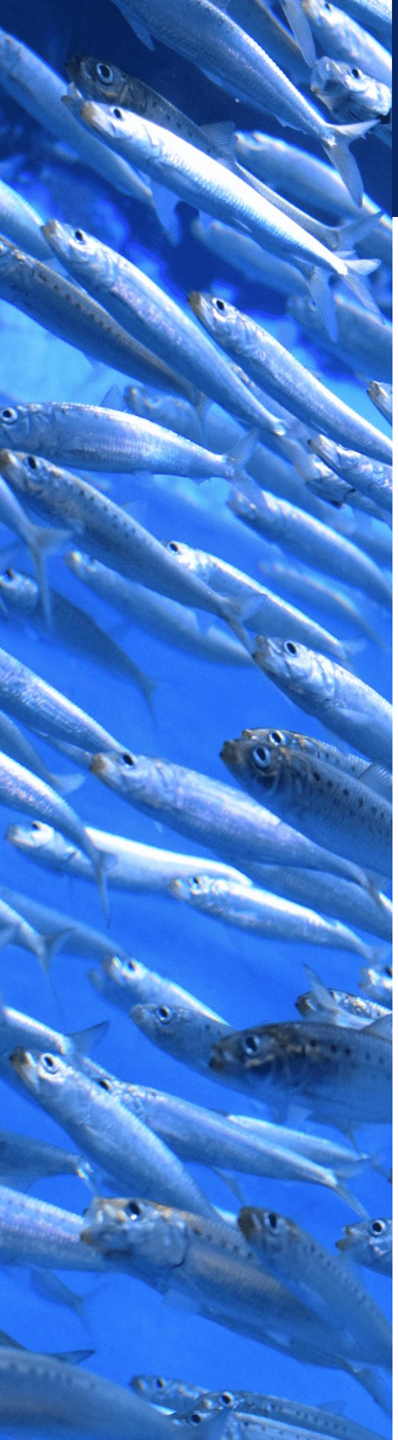
Results *Temperature effect on growth*



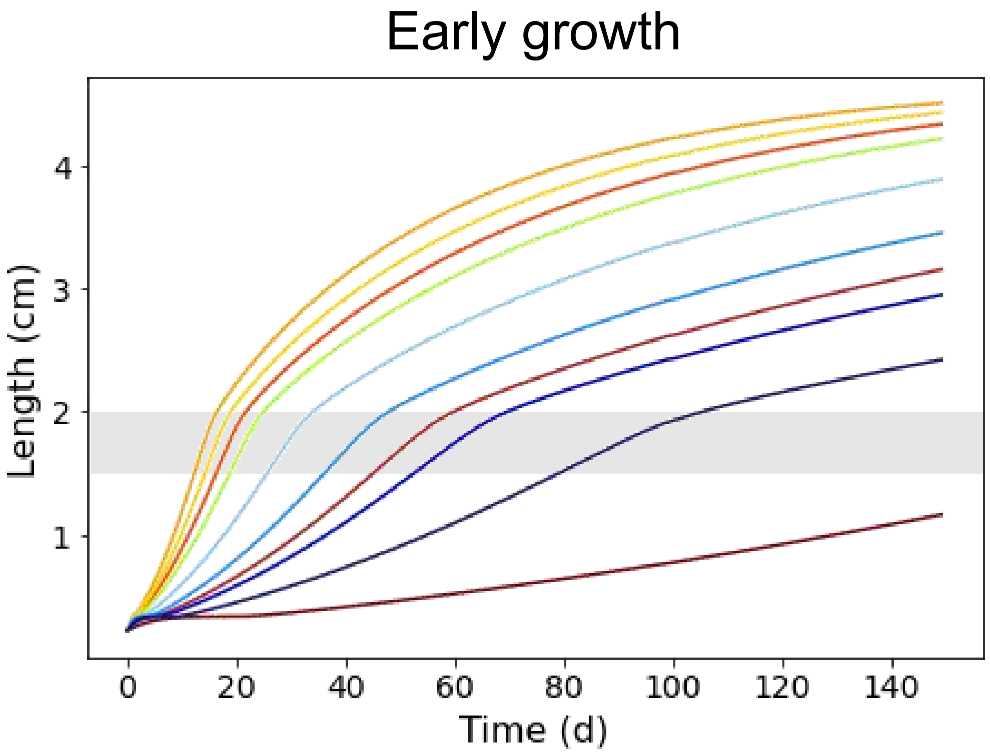


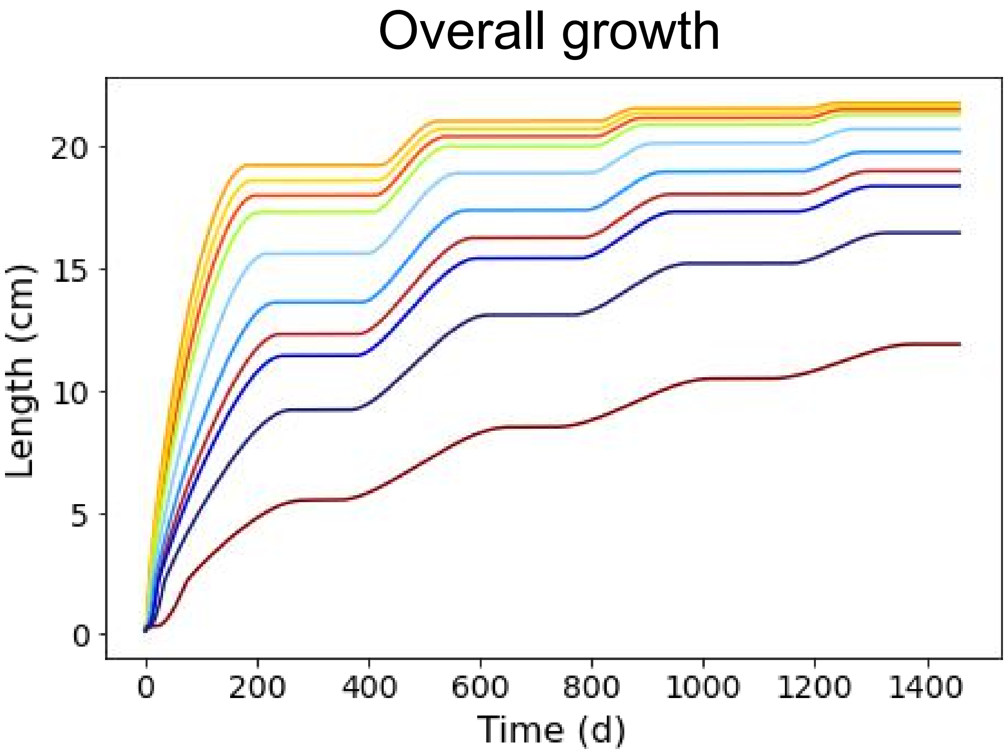
Ability to escape the viscous drag

> lower survival at extreme temperatures for early stages



Results *Temperature effect on growth*





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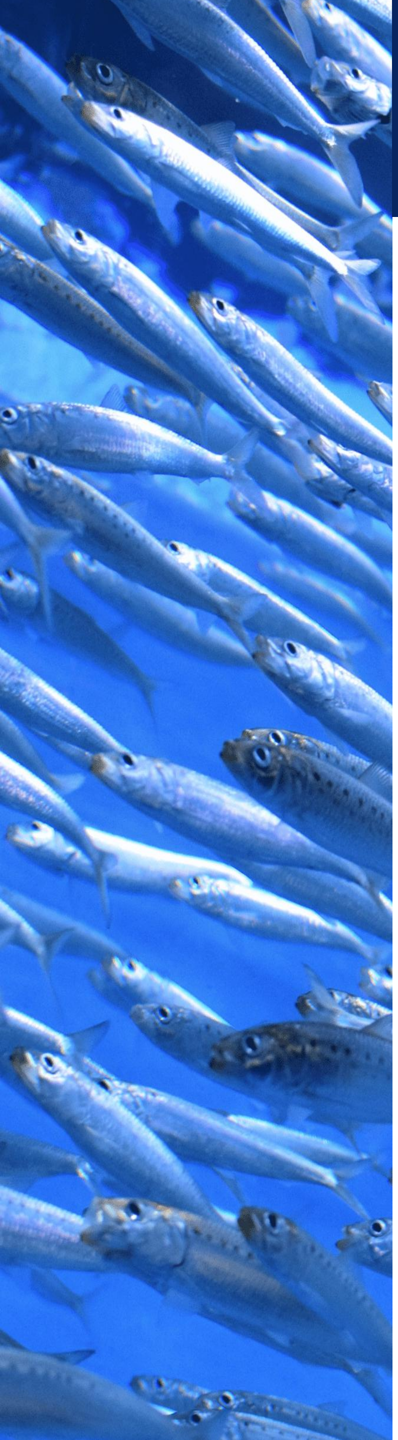
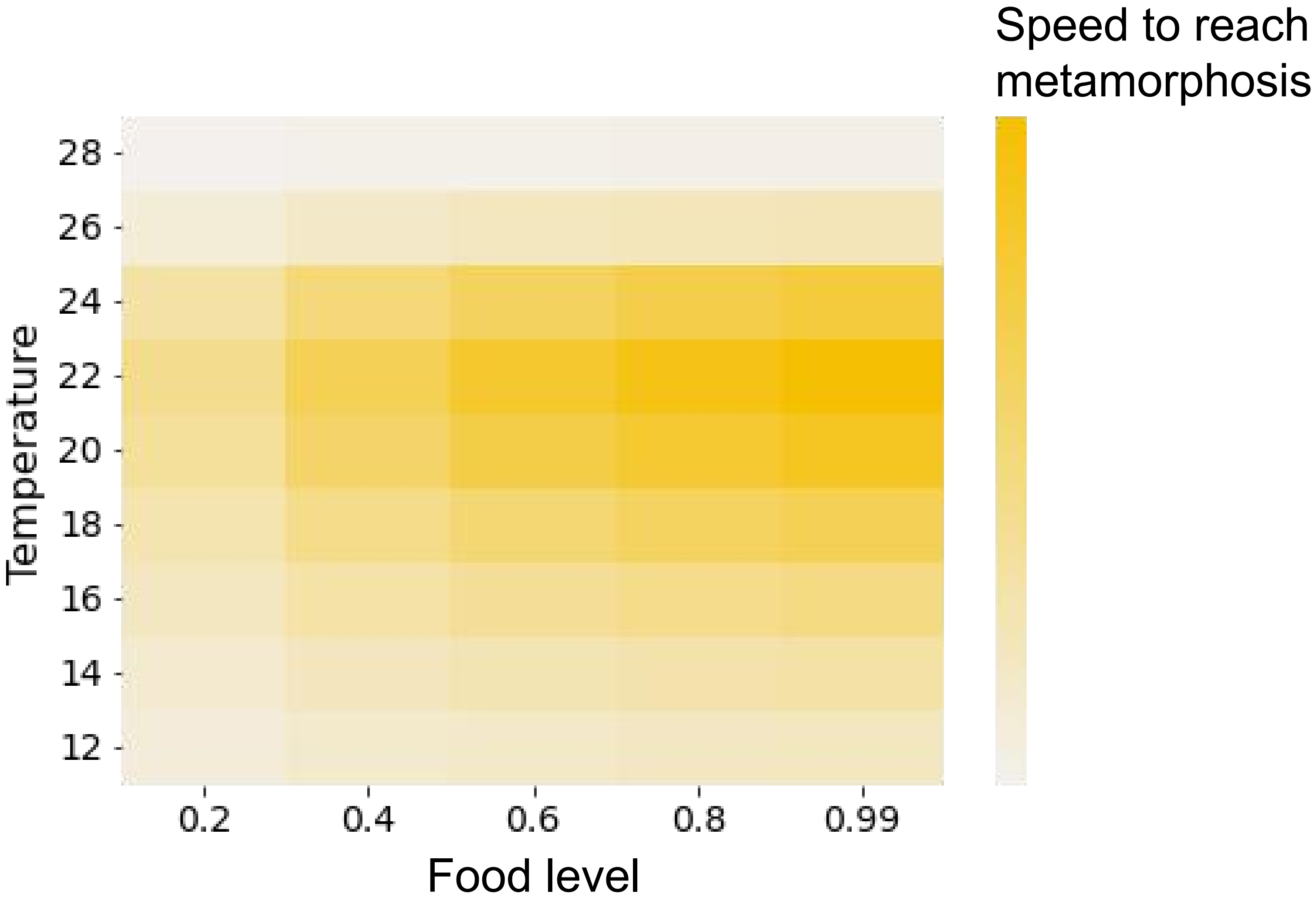
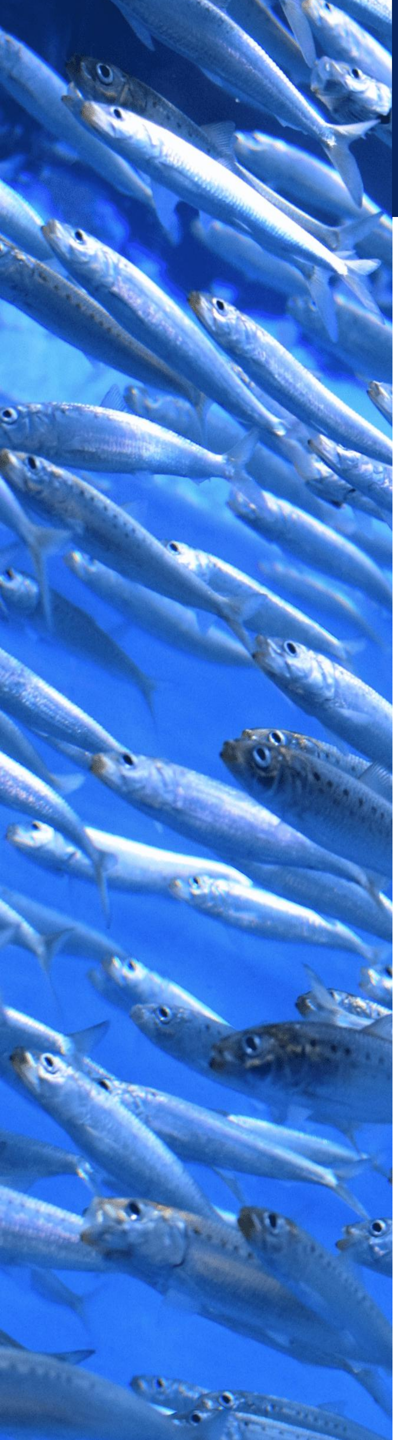


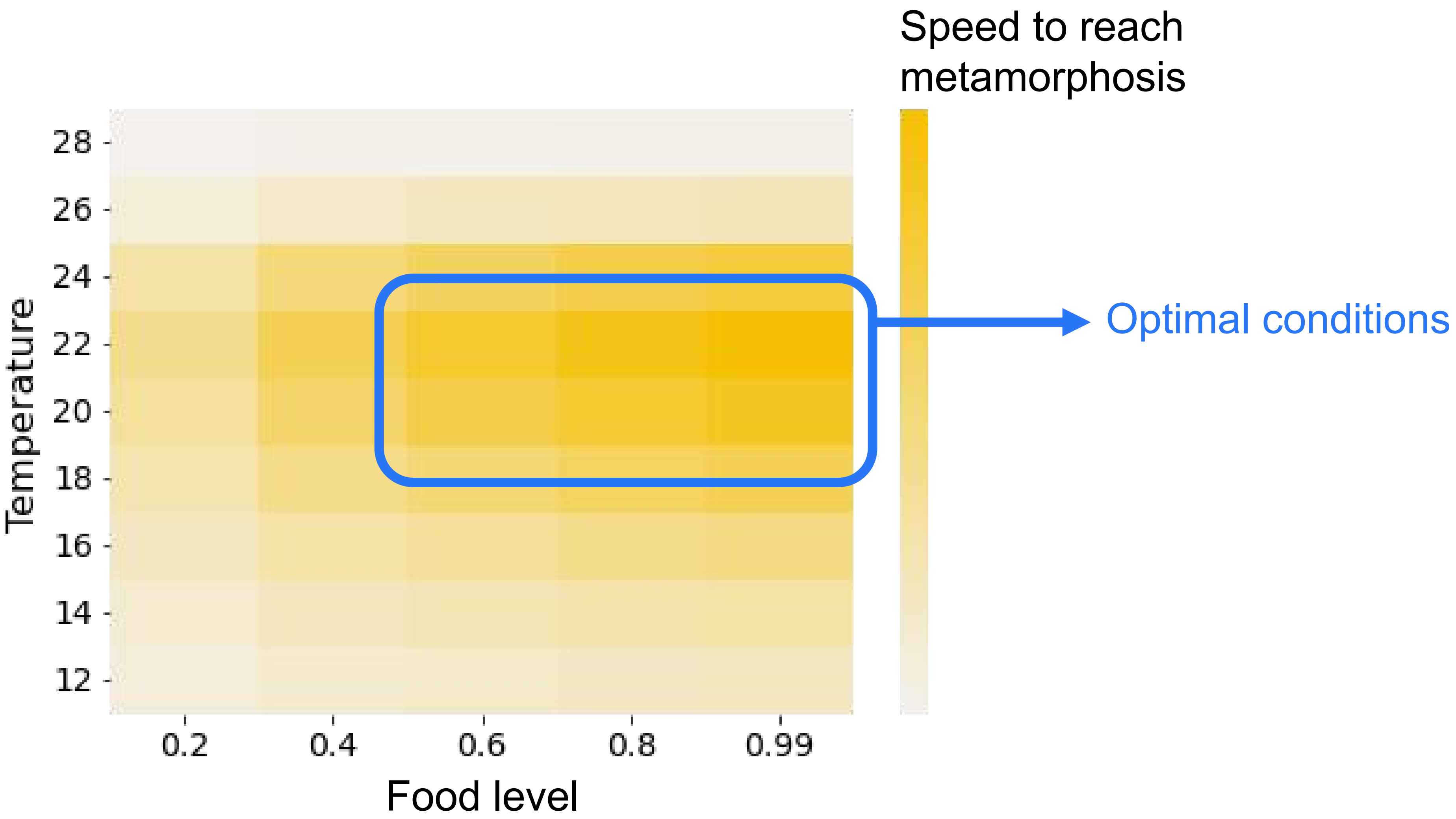
Results *Combined effect on metamorphosis*



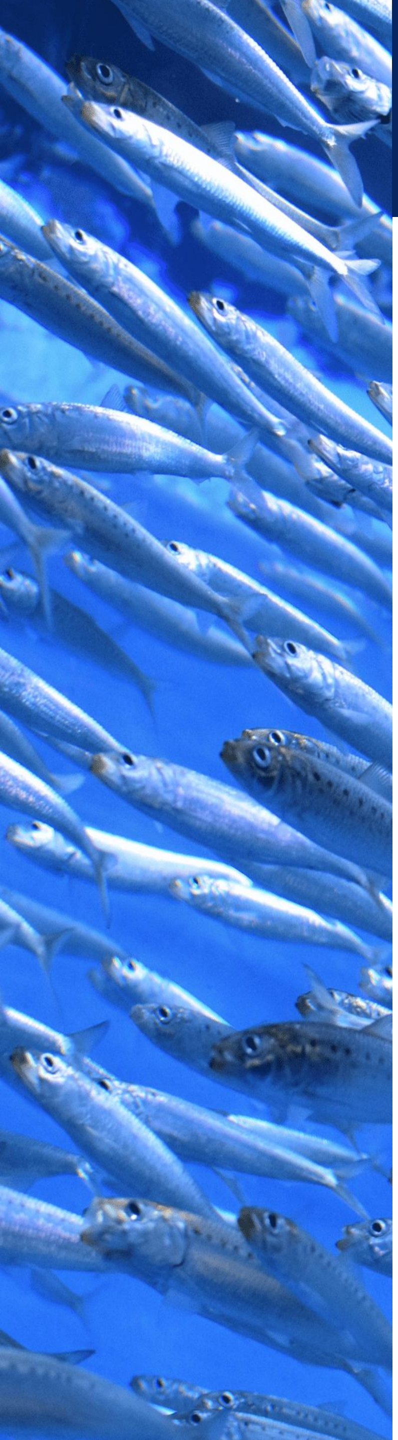


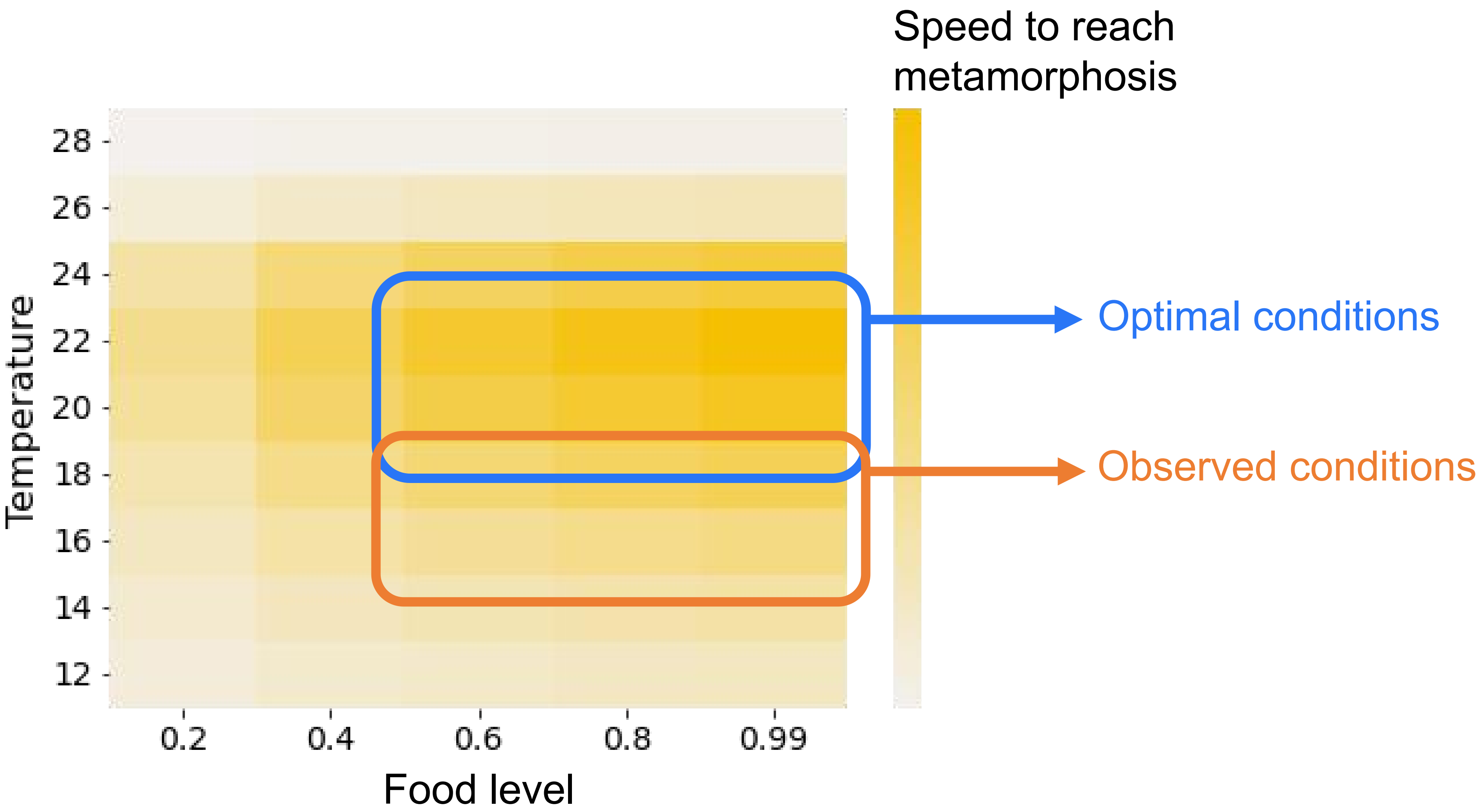
Results

Combined effect on metamorphosis



Results *Combined effect on metamorphosis*





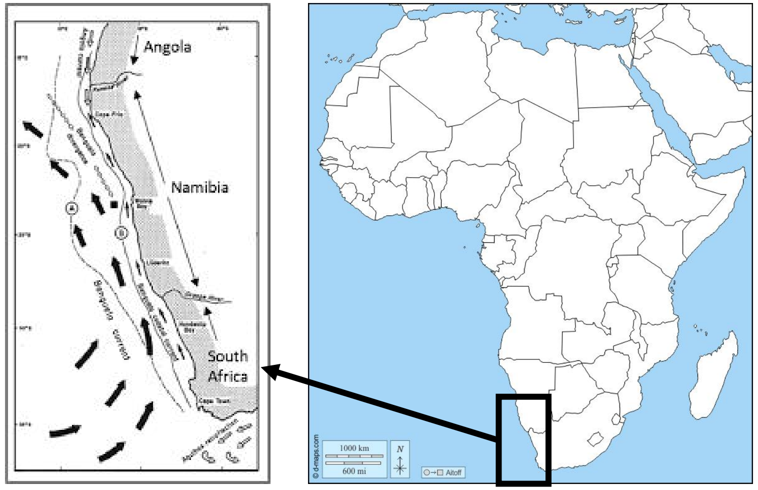
Discussion

Prospects

Impact of the other individuals/populations/communities on SPF variations ?

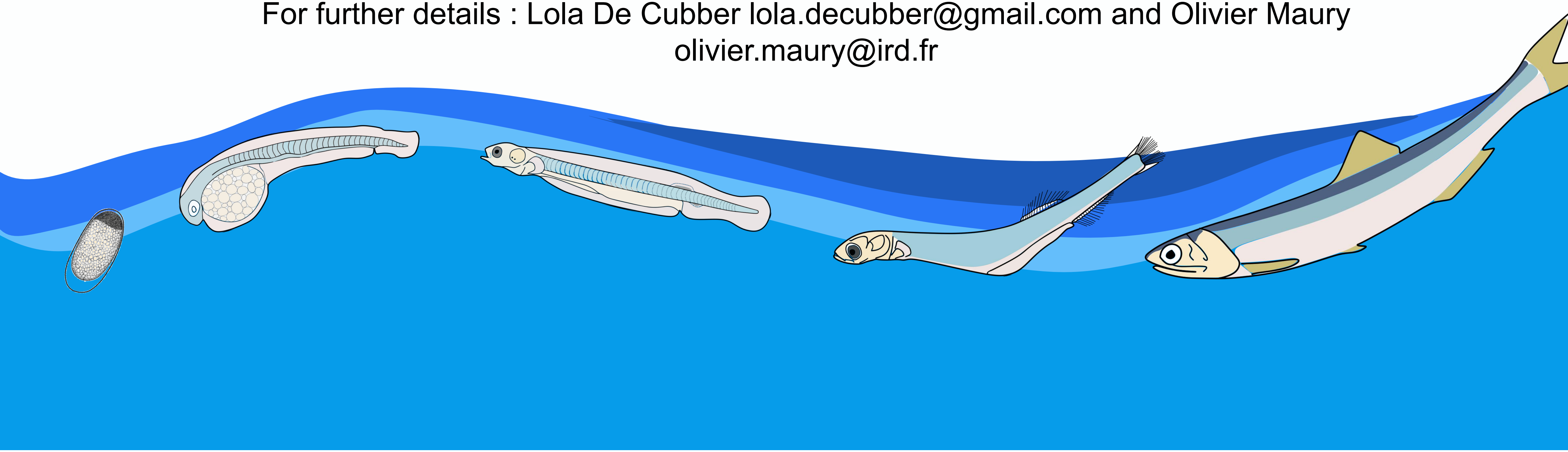
Integration within the APECOSM framework (focus species, Benguela encosystem)

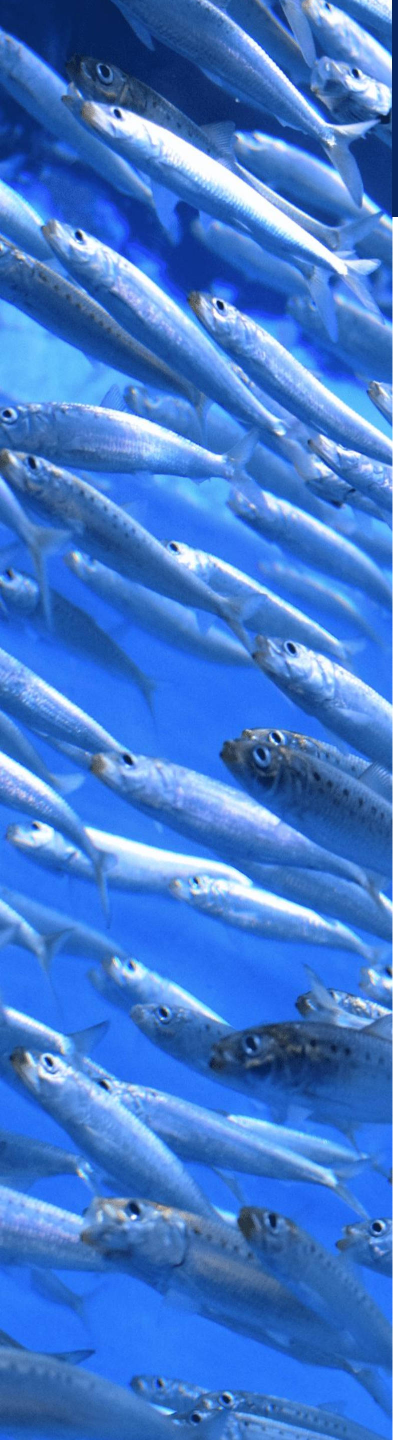
Represents the spatialized dynamics of open ocean pelagic ecosystems in the global ocean



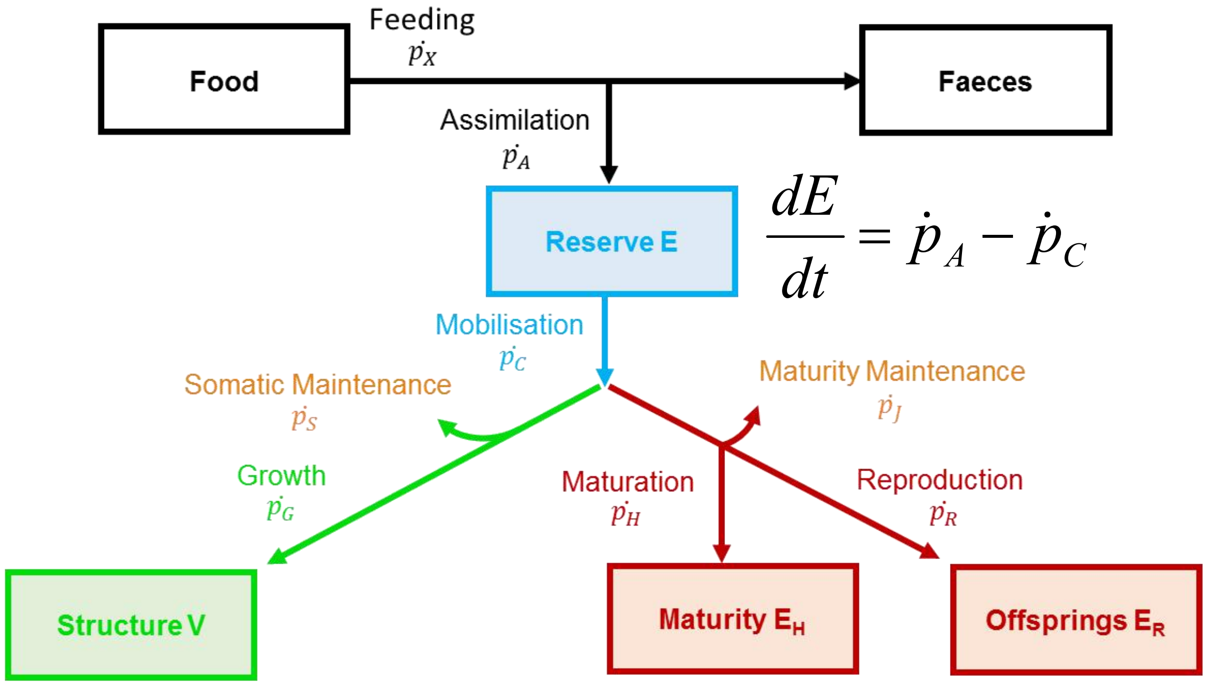
Merci !

For further details : Lola De Cubber lola.decubber@gmail.com and Olivier Maury olivier.maury@ird.fr





DEB model equations



$$\frac{dE}{dt} = \dot{p}_A - \dot{p}_C$$

$$\frac{dV}{dt} = \frac{\dot{p}_G}{[E_G]}$$

$$\frac{dE_H}{dt} = \dot{p}_H$$

$$\frac{dE_R}{dt} = \dot{p}_R$$

$$\dot{p}_A = \{\dot{p}_{Am}\} \cdot f \cdot S$$

$$\dot{p}_C = [E] \cdot \frac{[E_G] \cdot \dot{v} \cdot S + [\dot{p}_M] \cdot V}{[E_G] + [E](\kappa - \rho)}$$

$$\dot{p}_S = ([\dot{p}_M] + [\dot{p}_p]) \cdot V, \text{ with } [\dot{p}_p] = \frac{\rho \cdot \dot{p}_C}{V}$$

$$\dot{p}_J = \dot{k}_J \cdot E_H$$

$$\dot{p}_G = \kappa \cdot \dot{p}_C - \dot{p}_S$$

$$\dot{p}_R = (1 - \kappa) \cdot \dot{p}_C - \dot{p}_J$$

$$\dot{p}_H = (1 - \kappa) \cdot \dot{p}_C - \dot{p}_J$$

Impact de la température : équation d'Arrhénius

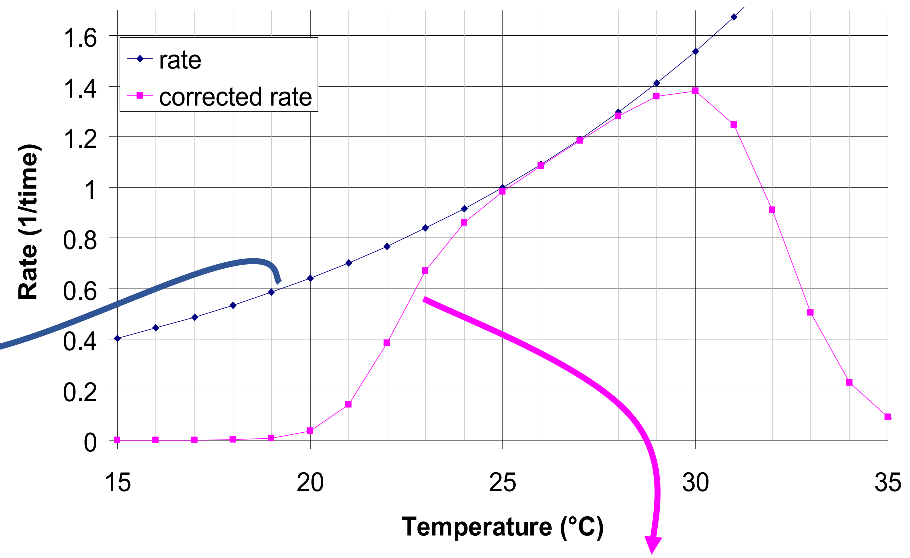
Les taux métaboliques (ou vitesse des réactions chimiques) sont affectés par la température suivant l'équation d'Arrhénius :

$$k(T) = k_1 \exp\left\{\frac{T_A}{T_1} - \frac{T_A}{T}\right\}$$

Température d'Arrhénius

taux métabolique à la température T

taux métabolique de référence à T1 ($T_{référence}$)



En général, en dehors d'un range optimal de température (T_L < Topt < T_H), les taux métaboliques diminuent :

- Températures trop basses ($T < T_L$) et solidification des membranes lipidiques avec diminution des flux membranaires
- Températures trop hautes ($T > T_H$) et dénaturation des enzymes (structures quaternaires)

L'équation devient :

$$r(T) = r(T_1) e^{\left(\frac{T_A}{T_1} - \frac{T_A}{T}\right)} \left(1 + e^{\left(\frac{T_{AL}}{T} - \frac{T_{AL}}{T_L}\right)} + e^{\left(\frac{T_{AH}}{T_H} - \frac{T_{AH}}{T}\right)}\right)^{-1}$$

T_{AH} Température d'Arrhénius quand $T > T_H$

T_{AL} Température d'Arrhénius quand $T < T_L$

Estimation des paramètres DEB

Paramètres

$\{\dot{p}_{Am}\}$: Flux assimilé max par unité de surface structurelle (J.d^{-1}.cm^{-2})

κ_X : constante de demi-saturation

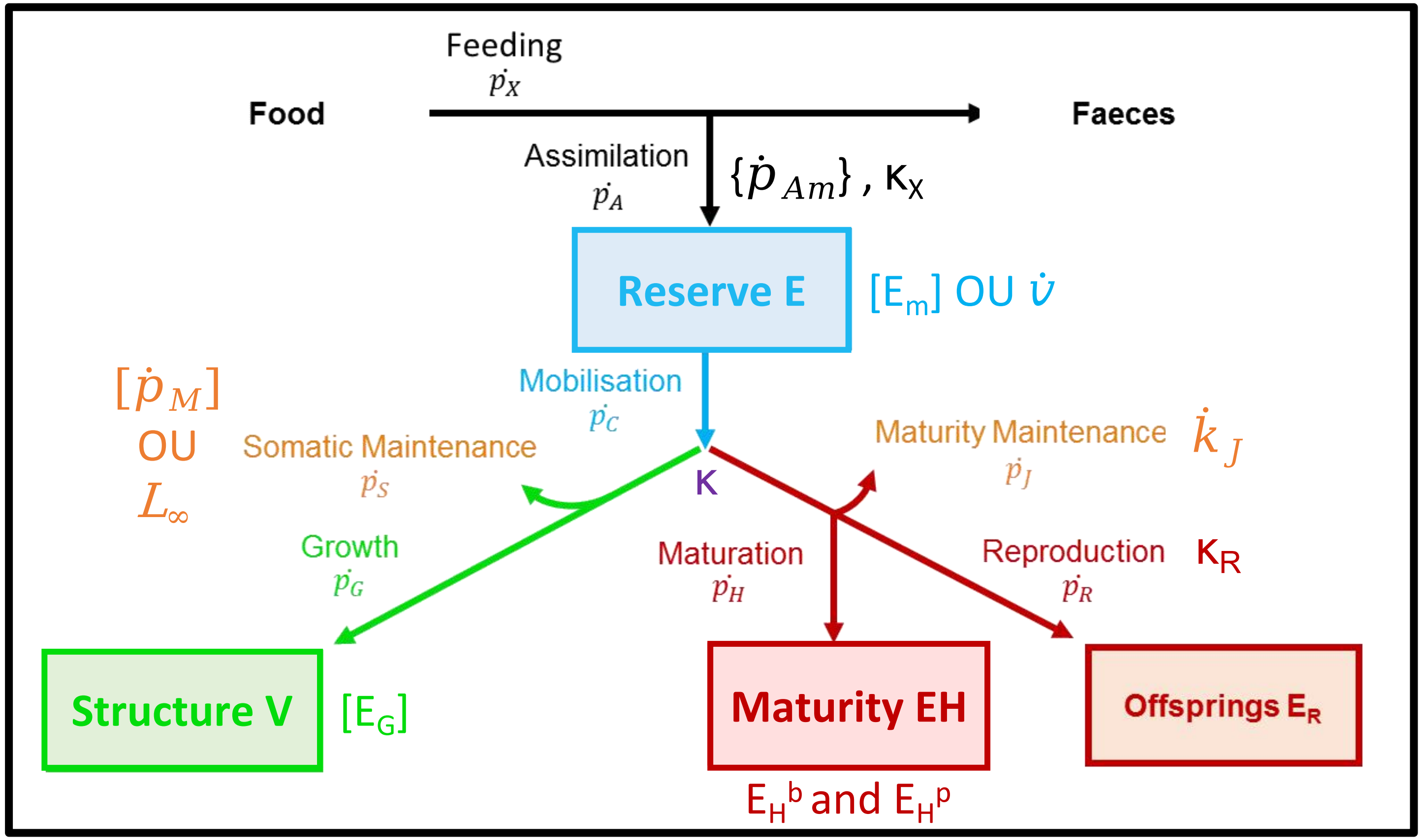
κ : proportion d'énergie allouée à la croissance

$[\dot{p}_M]$: taux spécifique de maintenance (J.d^{-1}.cm^{-3}) OU L_∞ : longueur structurelle maximale à l'infini (cm) avec $L_\infty = \frac{\kappa f \{\dot{p}_{Am}\}}{[\dot{p}_M]}$

$[E_G]$: couts spécifiques de structure (J.cm^{-3})

12 paramètres à ajuster dans un modèle standard

+ δ : shape coefficient + TA : Température d'Arrhénius (K)



$[E_m]$: densité d'énergie maximale des réserves (J.cm^{-3}) OU

$\dot{v}$: conductance énergétique (cm.d^{-1}), avec $\dot{v} = \frac{\{\dot{p}_{Am}\}}{[E_m]}$

$\dot{k}_J$: taux de maintenance de maturation (d^{-1})

κ_R : proportion of the reproductive energy allocated to the gametes

E_H^b, E_H^p : niveaux d'énergie dans le compartiment EH pour atteindre le first feeding et la puberté (J)

Croissance

$$\frac{dV}{dt} = \frac{\kappa f \{\dot{p}_{Am}\} V^{2/3} - [\dot{p}_M] V}{\kappa f [E_m] + [E_G]}$$

Quand la croissance atteint son max : $\frac{dV}{dt} = 0 \Rightarrow V_\infty^{1/3} = \frac{\kappa f \{\dot{p}_{Am}\}}{[\dot{p}_M]}$

Les corrections de températures appliqueée aux flux s'annulent

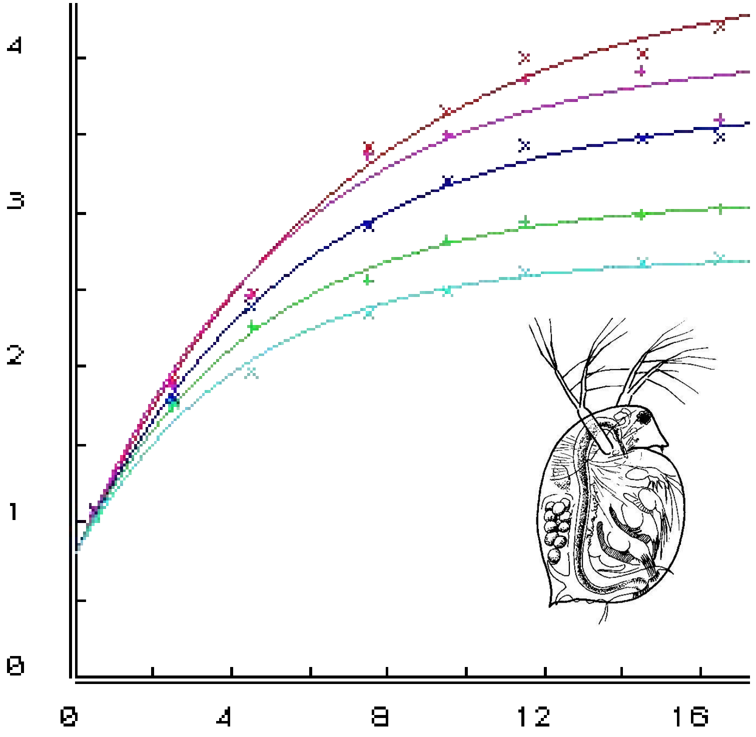
➡ **La taille à l'infini dépend uniquement de la quantité de nourriture**

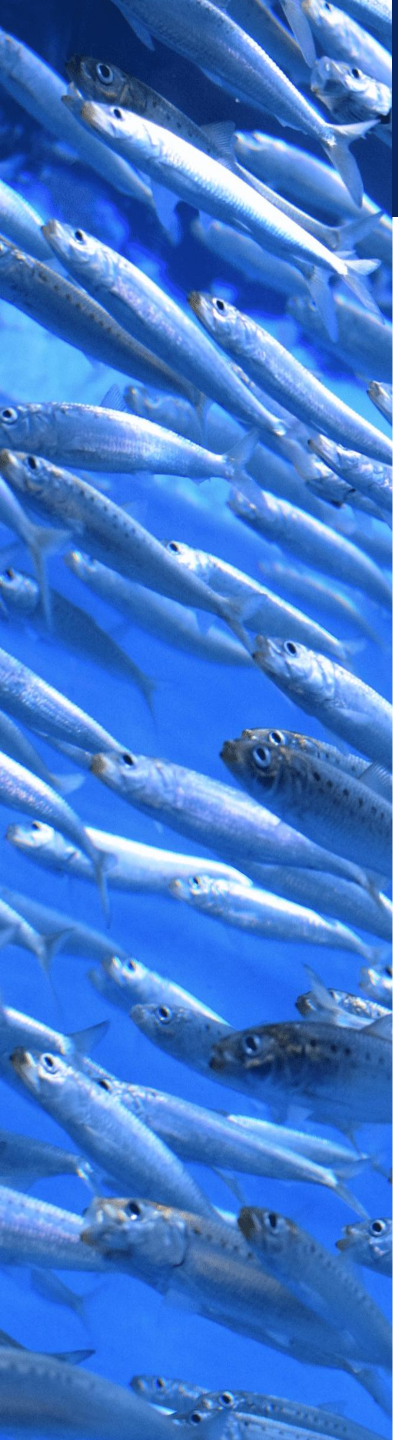
Analytiquement, on montre que le croissance de von Bertalanffy est un cas particulier du DEB à Température et nourriture constantes :

$$L_w(t) = L_{w\infty} - (L_{w\infty} - L_{wb}).exp(-r_B t)$$
$$r_B^{-1} = 3k_M^{-1} + 3\delta L_{w\infty} / v$$
$$L_{w\infty} = f L_{wm} = f V^{1/3}/\delta$$

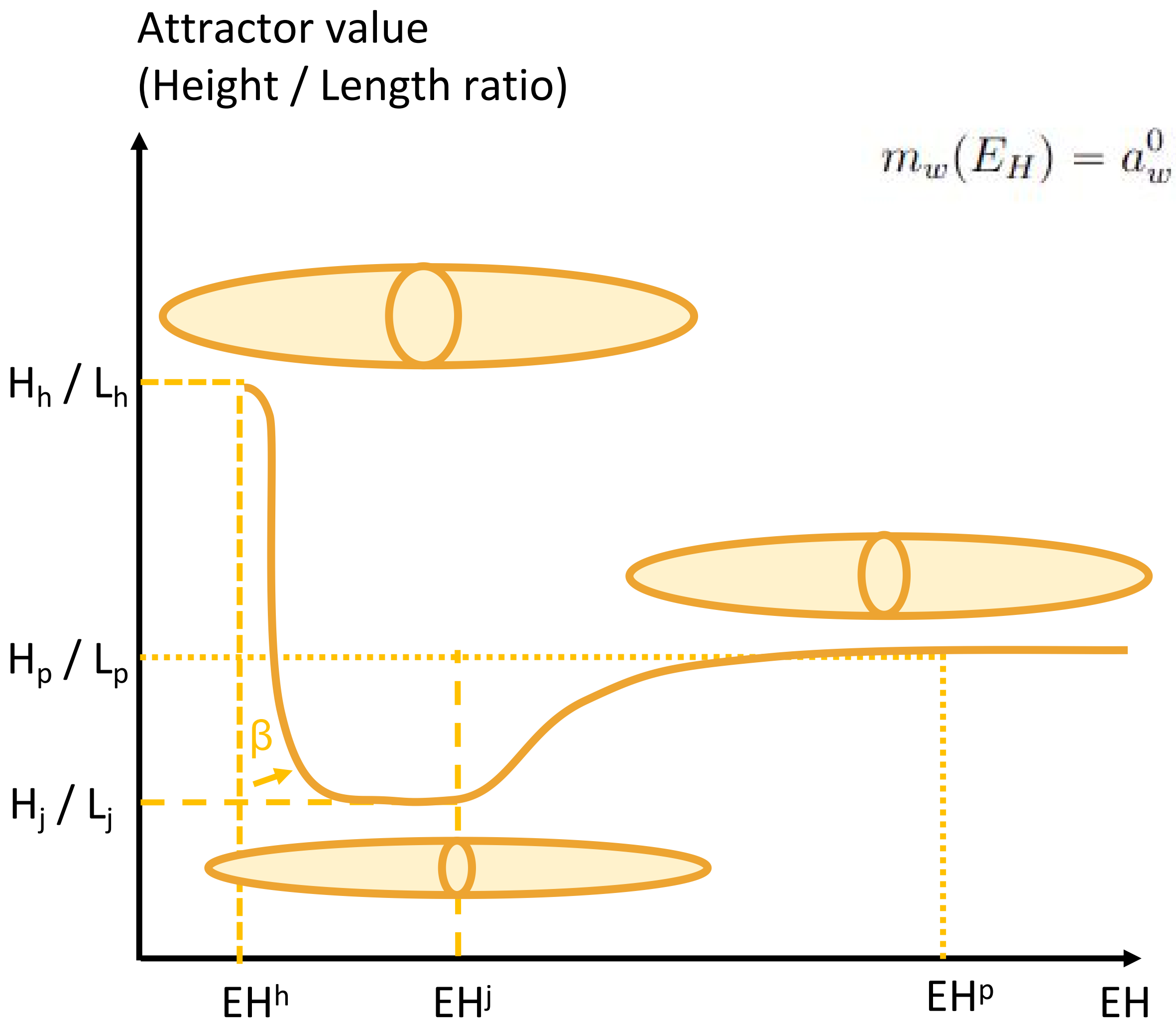
t	time	r_B	von Bert growth rate
L	Length	v	energy conductance
L_b	L. at birth	k_M	maint. rate coefficient
L_∞	ultimate L.	δ	shape coefficient

avec $V = L^3 = (\delta.L_w)^3$, L_w Longueur observée
L Longueur structurelle





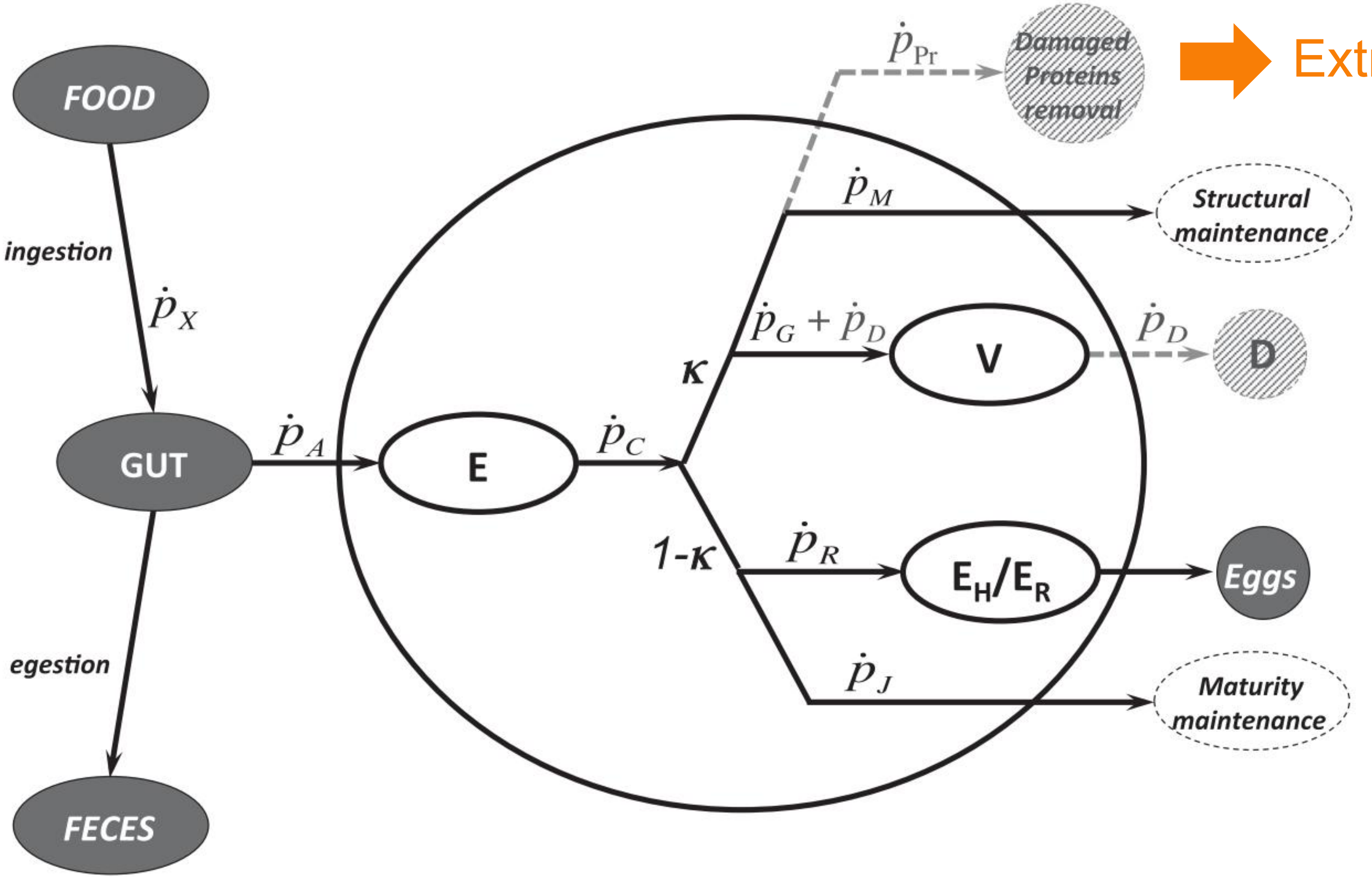
Methods



$$m_w(E_H) = a_w^0 + \sum_{k=0}^{k=p} \frac{a_w^{k+1} - a_w^k}{1 + e^{\beta \cdot \frac{E_H^{k+1} - E_H}{E_H^{k+1}}}}$$

Methods

Modified DEB with extra maintenance costs



Extra maintenance costs

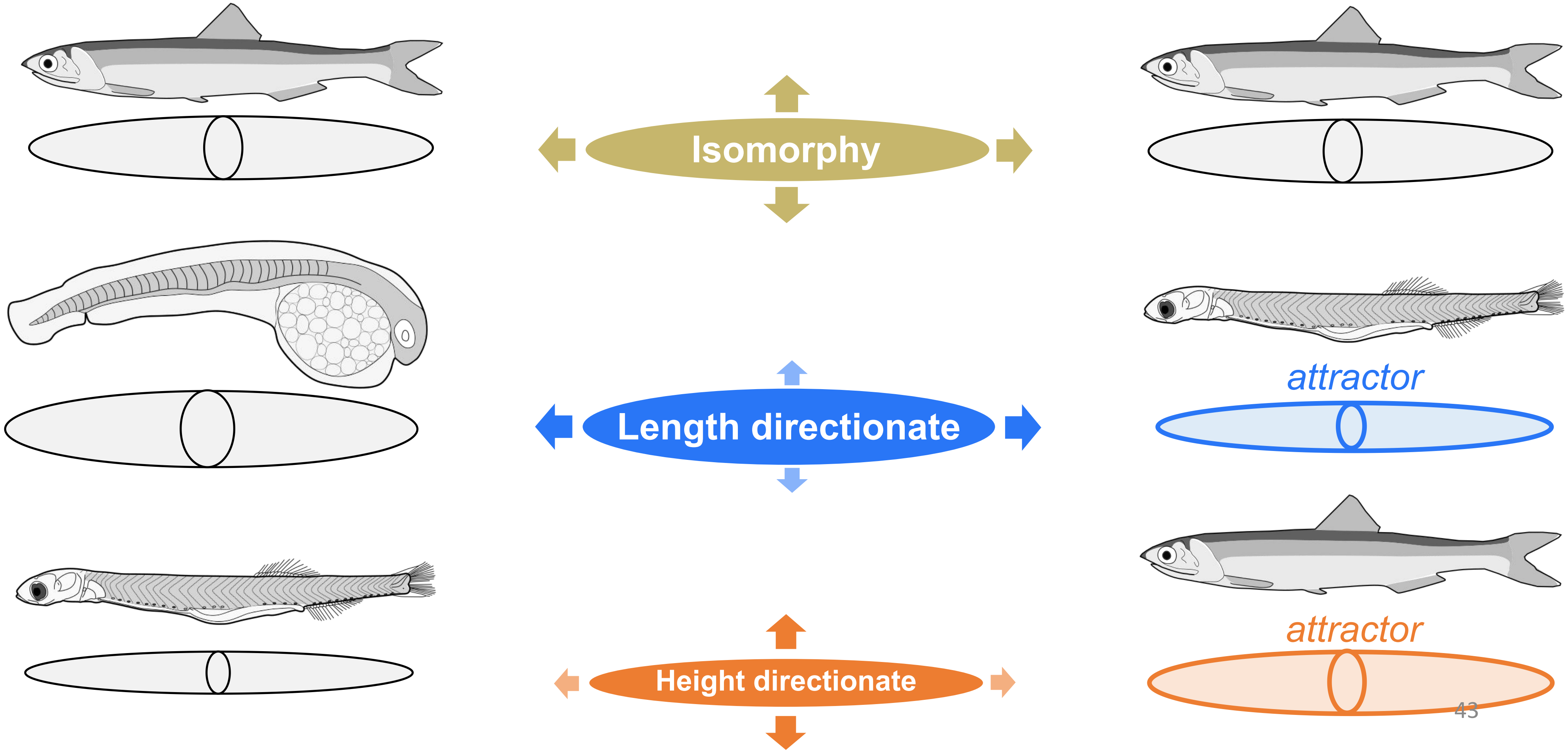
Restores the possibility of scaling some primary parameters to the ultimate length of the individual

Maury et al. (2017)

Methods

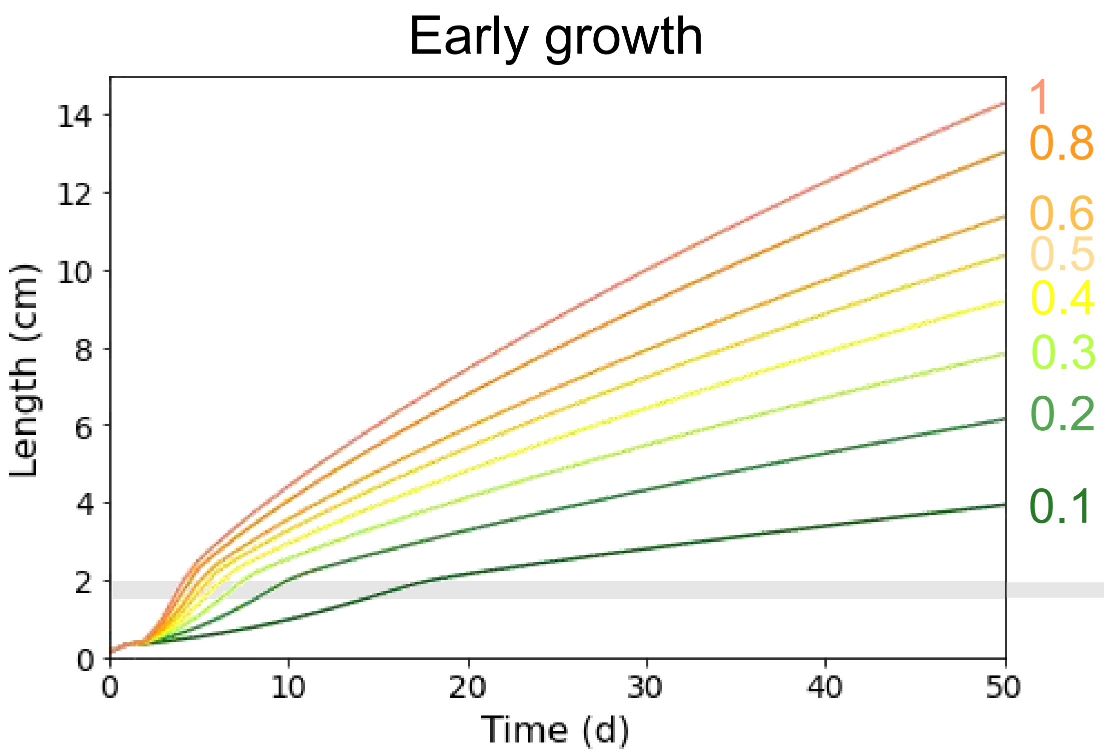
Growth types

$$\frac{dV}{dt} = \frac{\pi}{6}\left(H_e\, L_e\,\frac{dW_e}{dt} + W_e\, L_e\,\frac{dH_e}{dt} + W_e\, H_e\,\frac{dL_e}{dt}\right)$$



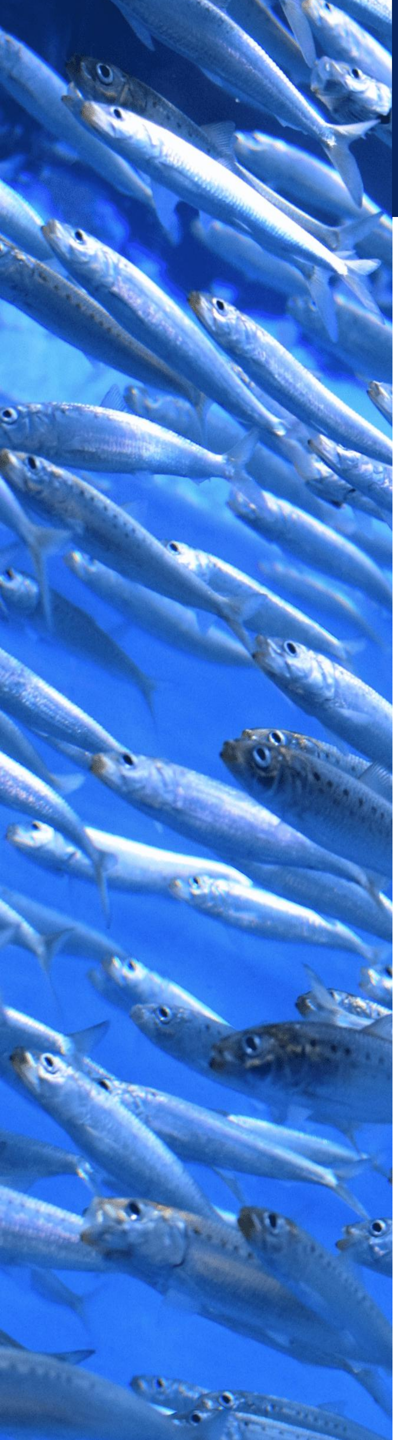
Results

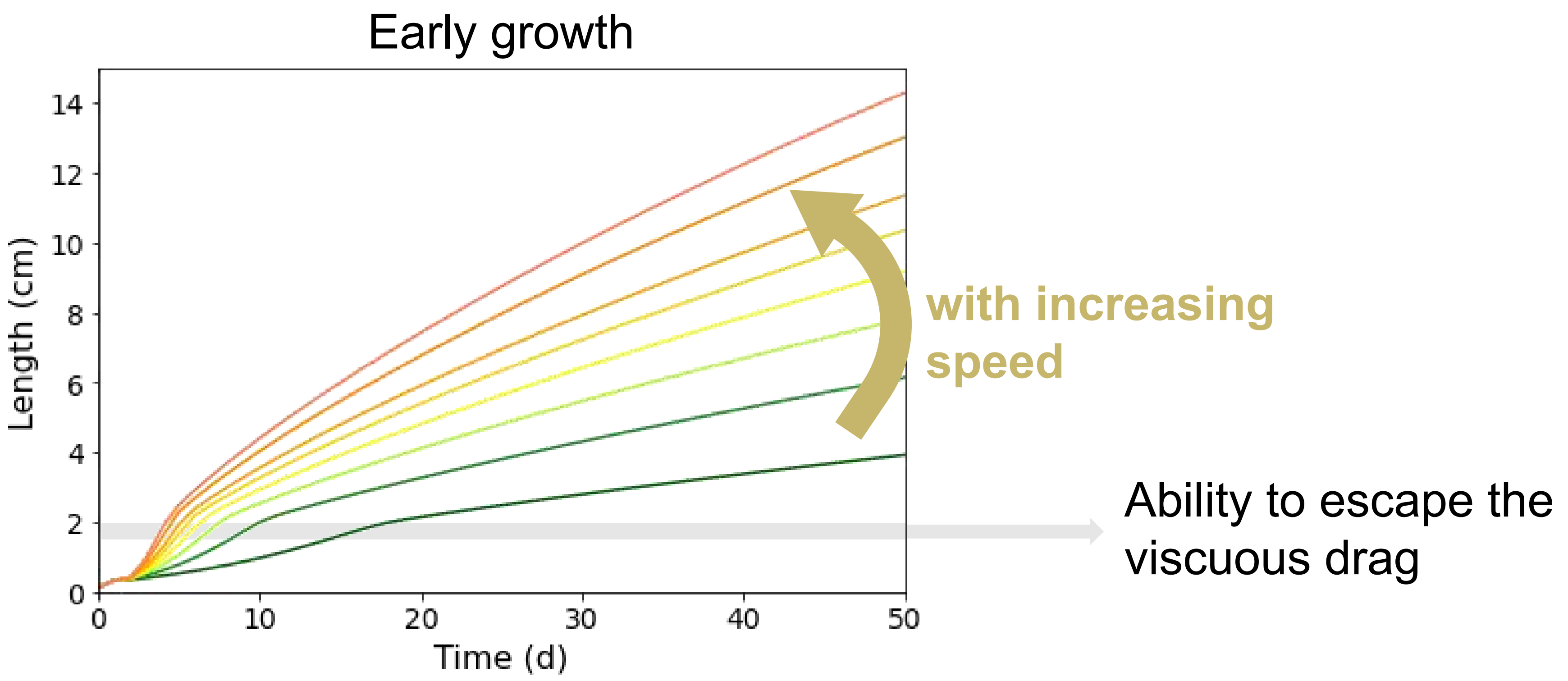
Food effect on growth

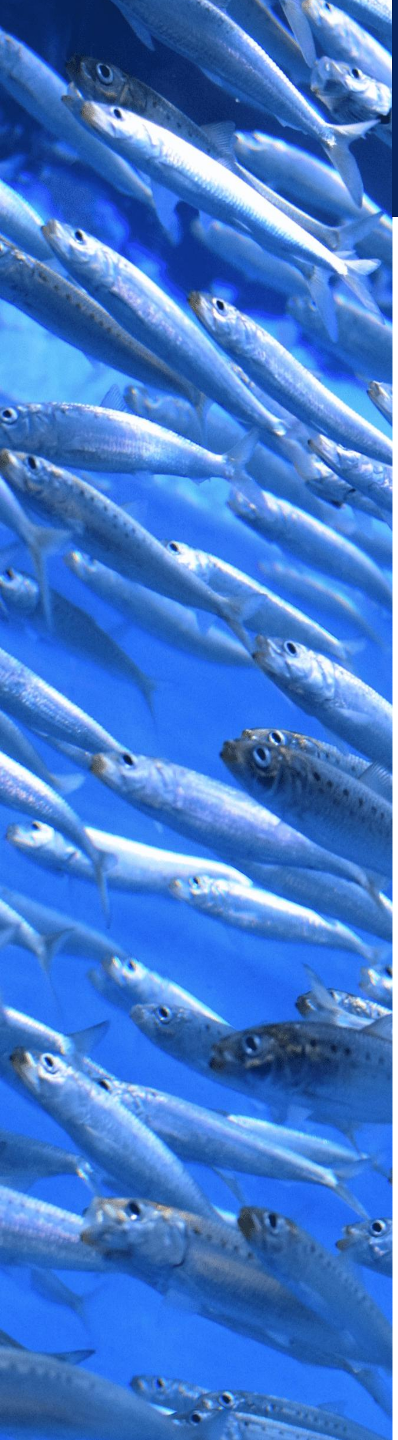


Ability to escape the viscuous drag

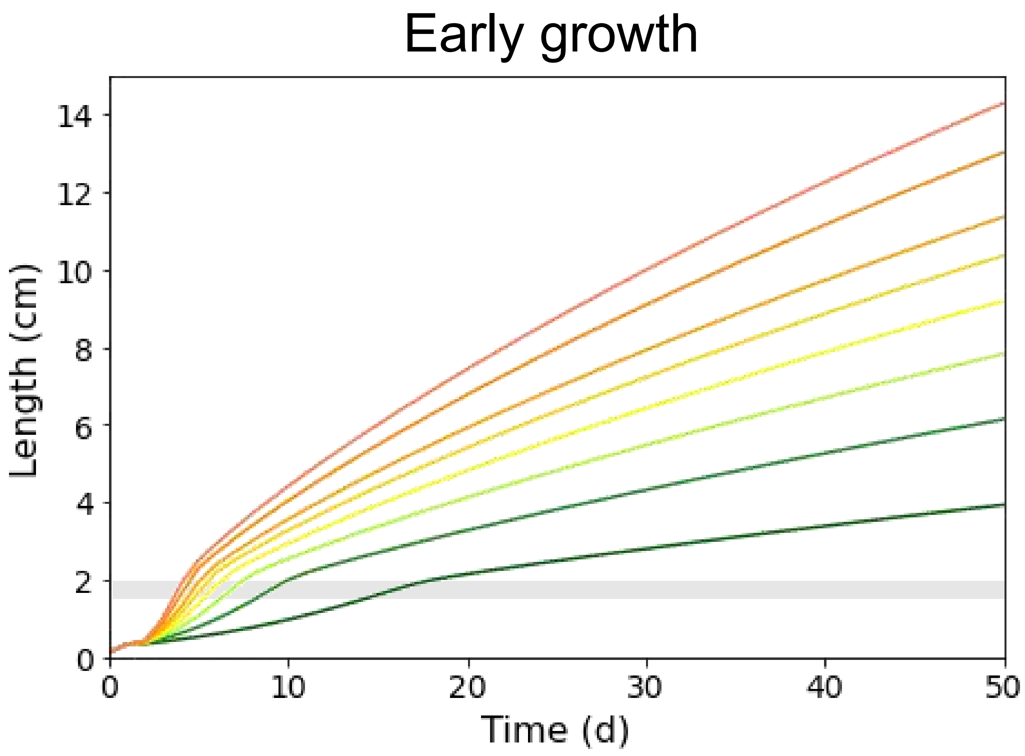
Food effect on growth

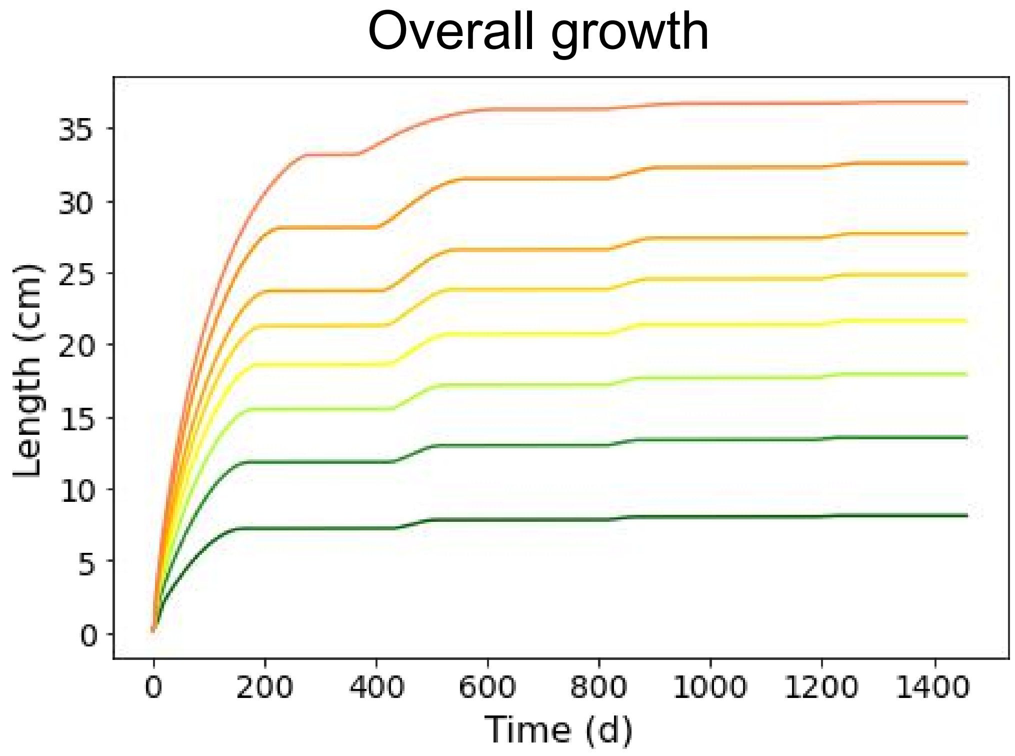






Results *Food effect on growth*





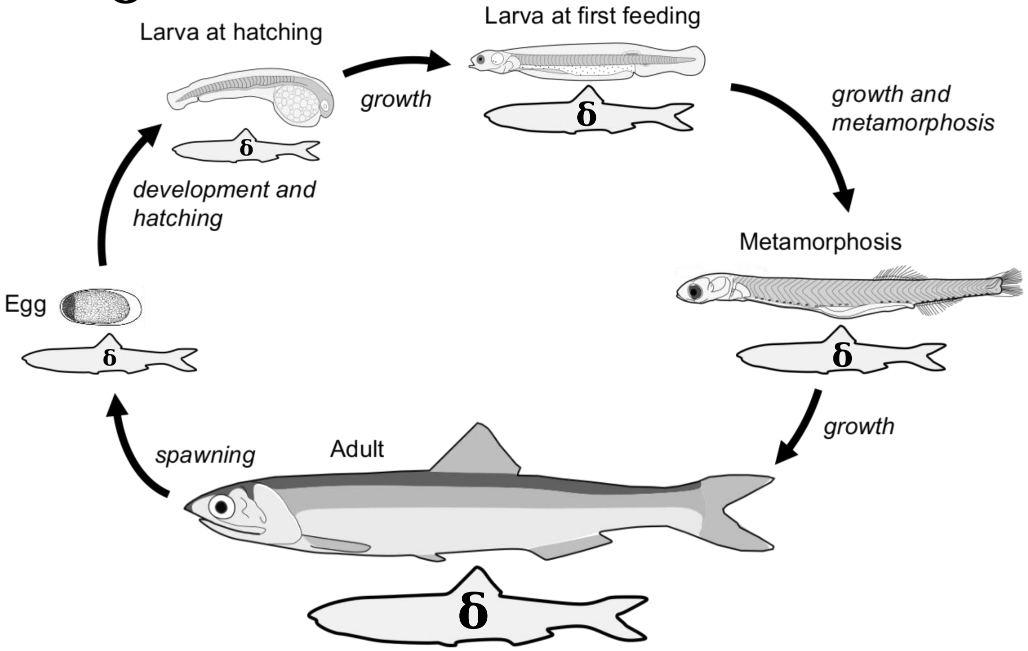
Introduction

Existing DEB models

Isomorphic DEB

~ constant shape coefficient

δ



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Isomorphic DEB

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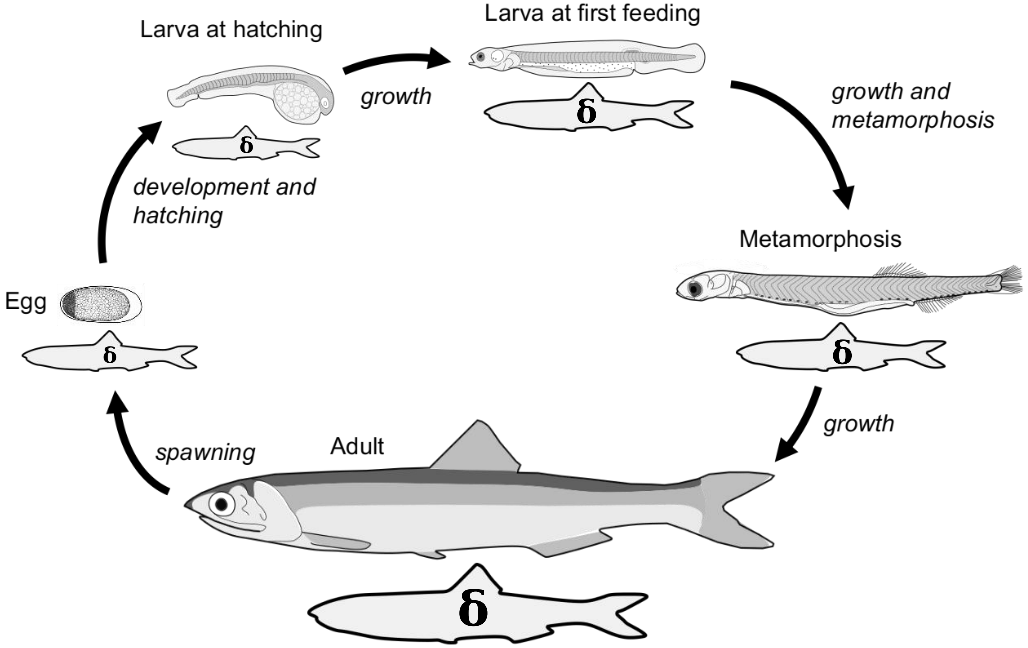
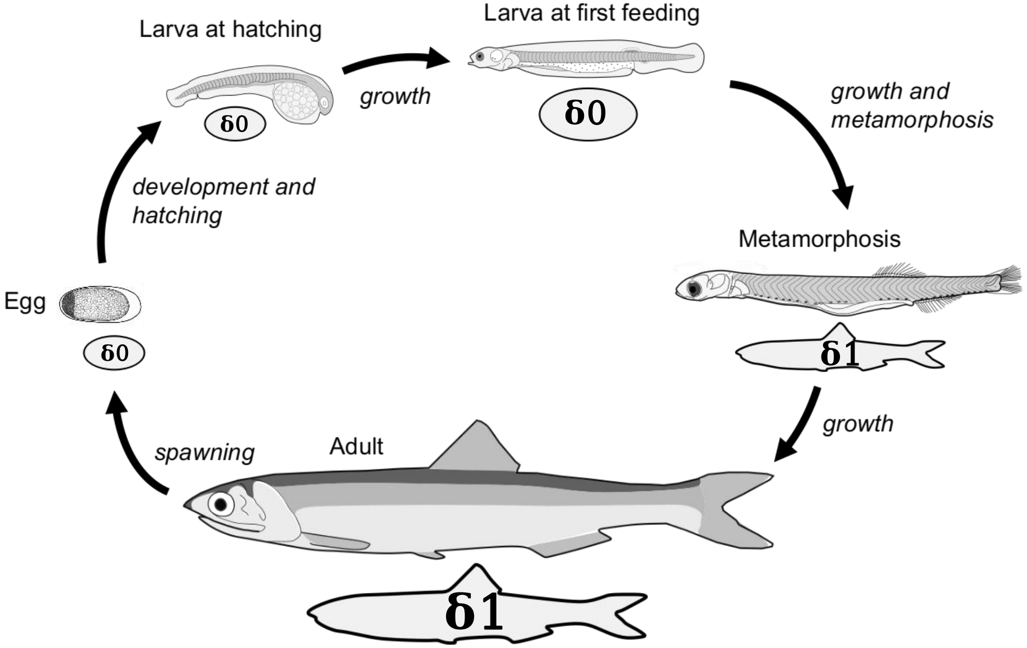
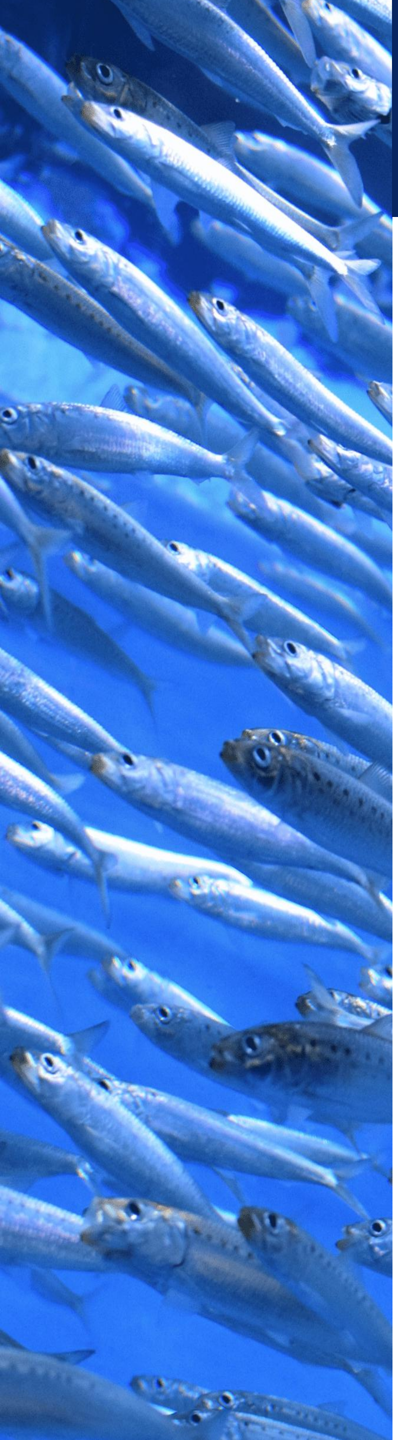


DEB with V1-morphy and metabolic acceleration





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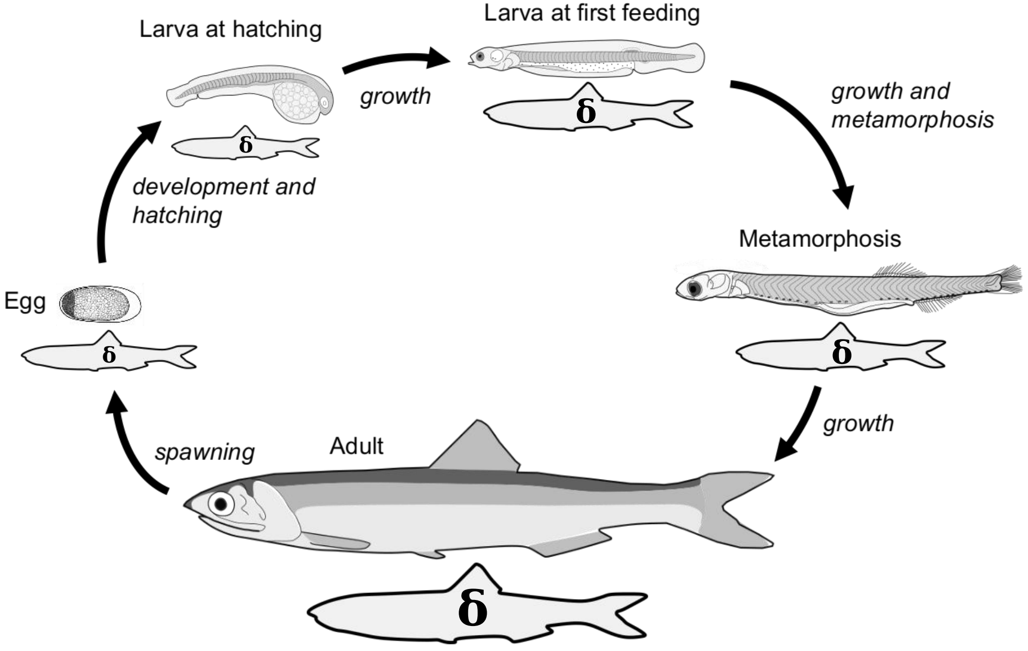

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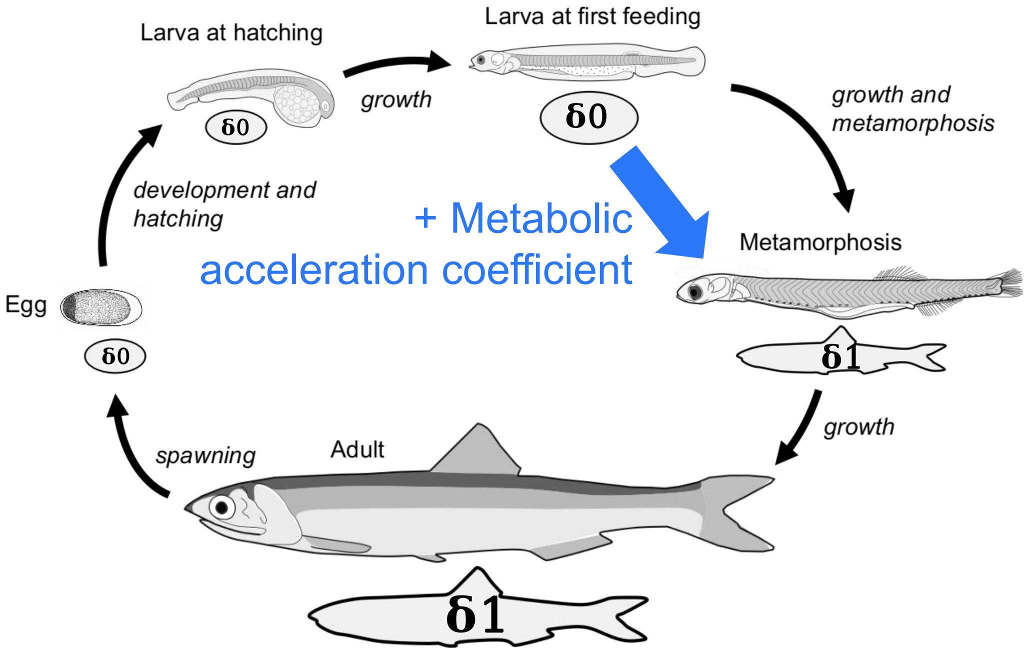

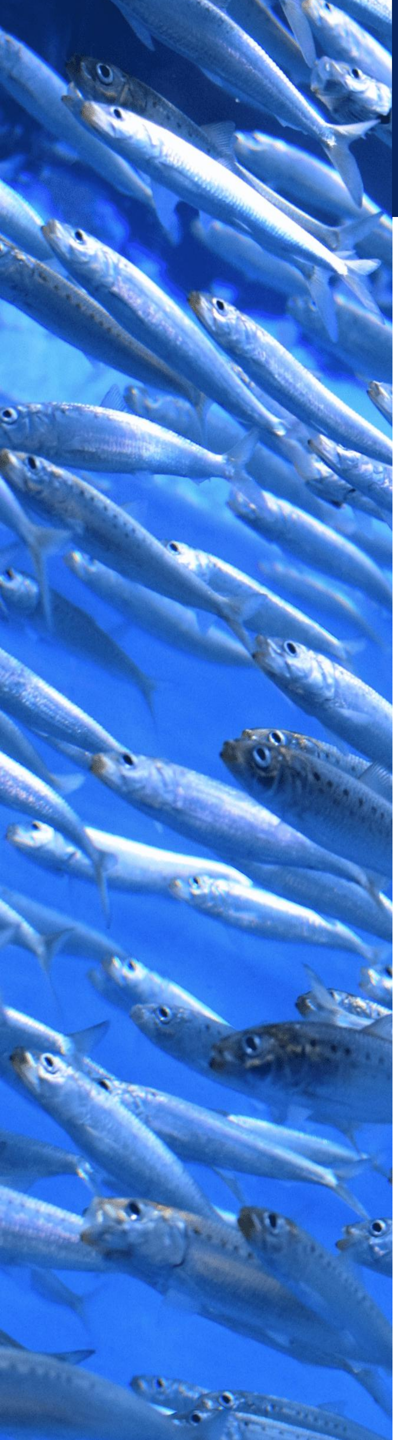

Introduction

Existing DEB models

Isomorphic DEB

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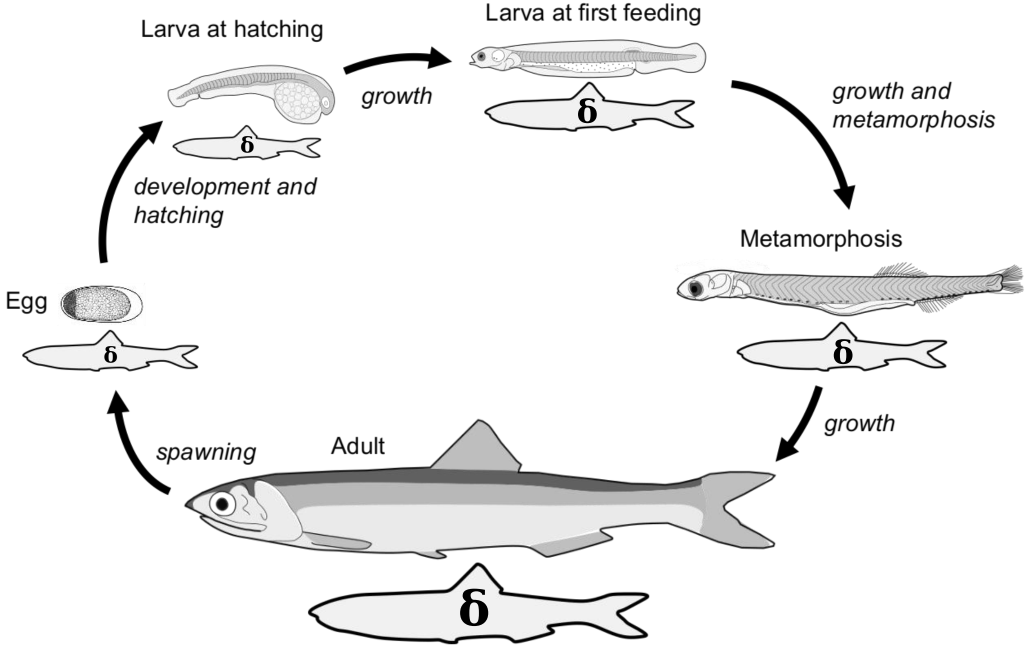
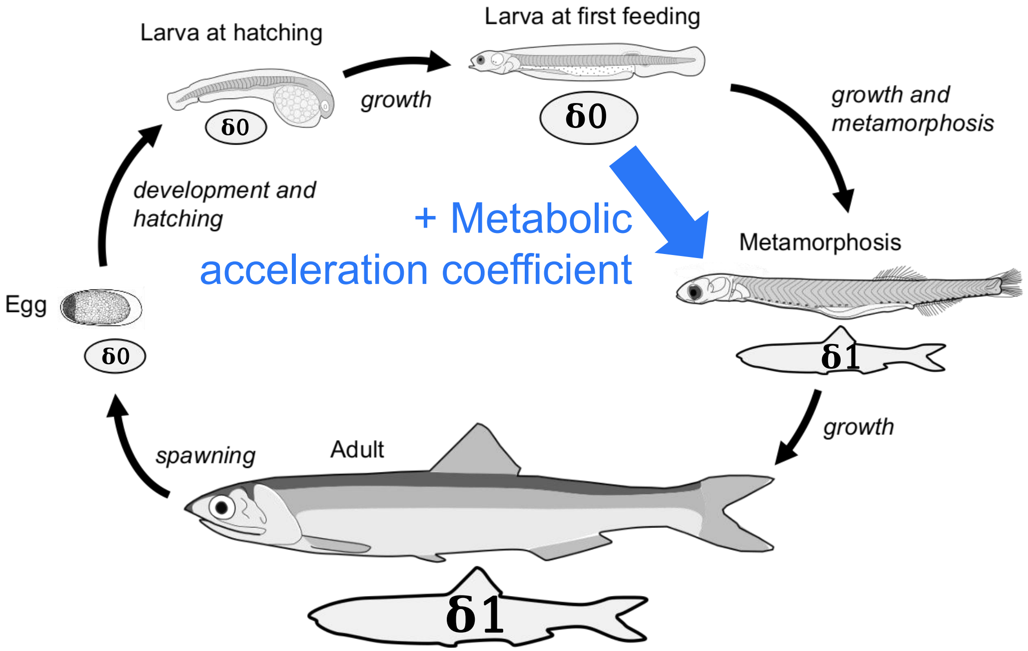


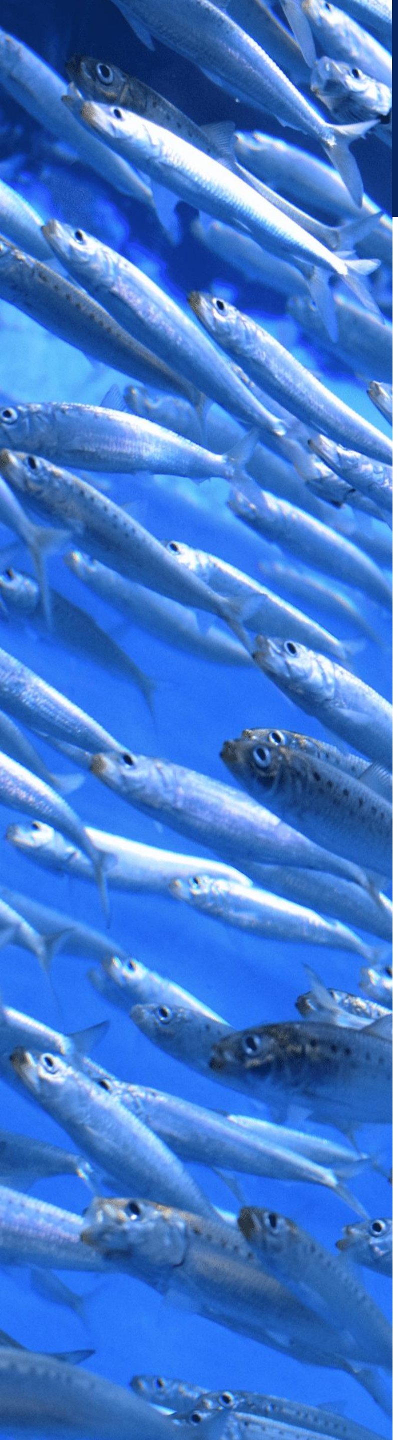
DEB with V1-morphy and metabolic acceleration



> Early stages shapes are not accurately represented

> Deviations from isomorphy are not accurately represented

> Metabolic rates are not defined ad hoc



Results

Model comparison

	Generalized	Isomorphy
pAm	51	1802.07
kX_adult	107	739
kX_early	181	419
Linf	27.6	27
Eg	294	376.70
Kappa	0.74	0.74